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A CENTURY OF PROGRESS SERIES

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A CENTURY OF PROGRESS SERIES

THE ROMANCE OF RESEARCH

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Baltimore, 1933
THE WILLIAMS & WILKINS COMPANY
IN COÖPERATION WITH
THE CENTURY OF PROGRESS EXPOSITION

Made in United States of America

Published August, 1933

Composed and Printed at the
WAVERLY PRESS, Inc.
for
The Williams & Wilkins Company
Baltimore, Md., U. S. A.

"The time will come when careful study through long ages will bring to light the secrets of Nature."—*Seneca*

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INTRODUCTION

THE economists of a century ago made much of the "law of diminishing returns." Originally applied to agriculture, it later found more general application. Simply stated, it is that in any constructive activity, under a given set of conditions, there is a point beyond which it does not pay to invest additional capital or labor. John Stuart Mill considered the law of diminishing returns to be "the most important proposition in political economy." "Were the law different," he wrote, "nearly all the phenomena of the production and distribution of wealth would be other than they are." Marshall who came after Mill and was the first to formulate the "law," recognized that its operation was suspended if there *happened to be* an advance in the art. Today the law of diminishing returns is being suspended with great frequency by the *law of increasing returns,* which declares that when the point of inefficiency has been reached, it pays, and that handsomely, to invest additional capital and labor in a systematized effort to gain and apply new knowledge, that there may be *brought*

about an advance in the art. It was the law of increasing returns that Liebig invoked in Mill's time and showed the world how, with relatively little extra capital and labor, to make two blades of grass to grow where one formerly had grown.

Systematized effort to gain new knowledge we call *research*. From it has come our progress in material welfare. What follows represents an attempt to convey the viewpoint of research, and something of its method, its development, and its achievements.

CHAPTER I

RESEARCH; ITS VIEWPOINT AND METHOD

"LIFE is short, experience treacherous, judgment difficult," said Hippocrates, Father of Medicine. Yet two thousand years later judgment was no less difficult, life no less short; the barber was the surgeon, and major operations were equivalent to death warrants; the physician, when he did not defer to the ancients, was still looking to chance experience for his knowledge; while Asiatic cholera stalked the land.

Then it came about that experience began to be supplemented by experiment: Vesalius introduced dissection; Harvey discovered the circulation of the blood; Jenner banished the hopeless terrors of smallpox; Pasteur, experimental chemist, turning to the study of microörganisms, laid the foundation of modern medicine; Lister, applying the new knowledge to his work with the scalpel, founded modern aseptic surgery—all in three hundred years, and simply because men began to observe closely and with open minds,

while they *caused* things to happen, instead of observing casually, with closed minds, and only when things *chanced* to happen.

Today enrichment of life proceeds at a rapid rate—but we are ahead of our story. We shall do better just now to consider more in detail why it is that we of today have all these benefits and more, while past generations had so few besides what Nature, unaided, was able to provide. Seemingly, these later days, man has substituted revolution for evolution and by arbitrary assumption of power over conditions has found himself able to apply Nature's laws with certainty and dispatch in the furtherance of his own creative purposes.

But what of the method by which men are thus creating, or rather by which they are helping Nature to create, a better physical environment for us all? If the desire is for something intrinsically new, whether an alloy steel, a synthetic dye, a radio tube, or a spineless cactus, it must be obtained, if at all, in Nature's prescribed way; it must be created; and nobody who is in a hurry to get something has ever been very successful in learning what way Nature prescribes. On the other hand, certain intellectually honest, enthusiastically persevering individuals, endowed with insatiable curiosity, keen power of observation,

ingenuity, originality, patience, common sense, and the urge to take infinite pains, have been notably successful in inducing Nature to reveal her secret ways of working. Furthermore, to such it is the best of all sports.

When Insatiable Curiosity undertook to learn from Nature he began to observe her closely and to record faithfully what he observed. When he wanted to learn more and learn it faster he invented experiment. Experience alone was not only too slow but was much less trustworthy. He learned that to be truly revealing, experiment must be carefully planned and controlled and the initial plan continually revised in the light of new facts as they come out of experiment. He learned that Nature, like us humans, can answer but one question at a time, so that if he wanted to learn the effect of more than one variable condition he could best do so by studying the influence of each separately, that is, by causing one at a time to vary and holding the rest constant. He learned, furthermore, the importance of "blank" or control experiments, particularly if there were a number of variable conditions whose influences were to be studied. He learned that, like any good general, he must have a well-thought-out plan of attack but must also be an opportunist, and change his plan to meet unexpected situations as they arise.

Still, the military metaphor is not altogether suited. When the experimenter is seeking new knowledge he is not attacking, he is interrogating. He is not in a belligerent but a happy mood. He is not even good-naturedly insisting on having his own way, but is ever ready to recognize a new fact when he sees it and has verified it; for, being intellectually honest, or, as we say, open-minded, he is seeking facts regardless of whither they may lead him.

One can hardly proceed in any exploration without some definite objective and some idea of what one is likely to find. So in his planning, our experimenter is best guided by an hypothesis concerning the interrelations of the phenomena he is about to study. Yet if he chance to unearth a new and upsetting fact, he promptly revises his hypothesis to accord with the new fact. The true experimenter never permits pride of opinion to outweigh love of the truth. He can be neither protagonist nor antagonist. He must be neutral, or win no case in Nature's court. He must have the aggressiveness of the prosecutor and the impartiality of the just judge.

If he is not open-minded, is not intellectually honest, he will be inclined to explain away an unexpected result; he may even refrain from recording it. In such case he really is only trying

to prove that his preconceived ideas were correct, which is another way of saying that he is no experimenter. Not only is he not playing the game, but he overlooks the fact that some of the greatest discoveries have come out of irregular results, results which were not rejected but were further investigated. It was only a slight irregularity found in the orbit of Uranus that led Adams and LeVerrier, independently, to discover Neptune. There was less than one per cent of a residue of inert gas that persistently remained when Cavendish tried by electric "sparking" to combine atmospheric nitrogen and oxygen. But he recorded and reported the fact and, a hundred years later, Rayleigh, repeating the experiment, found the residue to be mainly a new gaseous element, which he named Argon, and which we now use in gas-filled electric lamps. But this was not all; Ramsey was thus led to discover in our atmosphere a whole series of inert elementary gases; among them Neon, employed in the orange-red lights seen on every business street to-day. It was from the detection of otherwise unexplained lines in the solar spectrum that helium was discovered, though no one felt sure at the time that it was not peculiar to the sun. Later Rayleigh discovered traces of it in the air, and Cady and McFarland, again by not overlooking

small residues, found it in natural gas. To-day our government separates it for use in dirigibles, since it has nearly the buoying power of hydrogen and is non-inflammable. All this came about because painstaking experimenters observed closely, and recorded faithfully what they saw.

Many important discoveries have come unexpectedly, but they would probably have been missed by other than the seeing eye and alert mind of the trained observer. As our own Joseph Henry, contemporary of Faraday in the early work with electricity, put it: "The seeds of great discoveries are constantly floating around us, but they only take root in minds well prepared to receive them."

Experiment conducted for the discovery of new facts and their relation to other facts is scientific research. Behind it all is the well founded conviction that there is order in all natural phenomena. Close, accurate observation is always assumed.

We have been discussing the value of close observation and experiment, initially small-scale experiment; but experiment is not always possible. When it can be employed, it is the most direct and fruitful method of fact-finding. When it has very limited application, as in sociologic research, we have to fall back on careful, detailed

record of many observations of naturally occurring events related to the problem under investigation; then by so-called statistical methods endeavor to arrive at significant relationships, which would escape ordinary, hit-or-miss observation. The greater the number of cases studied and the more widely varied the setting, the more revealing the results. Facts, thus obtained, as with facts coming out of experiment, may on close analysis suggest a working hypothesis, which in turn may be expected to lead to further fact-finding and possible revision of such hypothesis.

A well established hypothesis is known as a theory, and a true and tried theory, a law.

As already stated, there is more to research than mere fact-finding. The facts must be interpreted, their relations to other facts pointed out; otherwise they will be of no value to science. Also, successful research calls for all of the faculties of an alert mind—penetrating analysis and deduction supplementing close observation, and, for the greatest strides in science, the vision to construct clarifying generalizations, or hypotheses, as guides to further fact-finding. We always get back to fact-finding as the only basis of fruitful generalization. There never was any trouble in constructing an hypothesis merely

consistent within itself, and never any progress achieved that way.

But fact-finding must not be thought of as pure drudgery. While no work demands greater devotion, in none is devotion more freely given. E. Emmet Reid, in his *Introduction to Organic Research* says: "Those who love hard work and love it all the better because it is hard, those who try and fail and keep on trying, those who can suffer the loss of months of hard labor and start all over again, those who cannot be discouraged no matter what happens, are invited to undertake research."

This, of course, is a description of appearances only, a view from the outside. The "slaves" of research are not driven from without but from within. They deserve our gratitude, but ask no sympathy for their lot. This is a true picture only of what is going on in the *workshop* of the researcher. The important happenings are inside the man. There, for every self-sacrificing act there is an impelling urge; for every determined rise above failure there is in waiting the more-than-compensating joy of having created.

None is better qualified to bear testimony than is Pasteur; listen to his appraisal of the lot of the researcher:

"It is indeed a hard task when you believe you

have found an important scientific fact and are feverishly anxious to publish it, to constrain yourself for days, weeks, years sometimes, to fight with yourself, to try to ruin your own experiments and only to proclaim your discovery after having exhausted all contrary hypotheses.

"But when after so many efforts, you have at last arrived at a certainty, your joy is one of the greatest which can be felt by a human soul, and the thought that you will have contributed to the honor of your country renders that joy still deeper."

It has been truly said that the great events of history are its great scientific discoveries. "In our century science is the soul of the prosperity of nations, and the living source of all progress. Undoubtedly the tiring daily discussions of politics seem to be our guide. Empty appearances!—What really leads us forward are a few scientific discoveries and their applications."—Again, Pasteur.

The best picture we have seen of the researcher's work shop and what may come out of it, is that given by Whitney and Hawkins, writing in *Profitable Practice in Industrial Research.* Under the caption, *Story of One Laboratory Table,* we read: "On that table there is nothing spectacular, nothing making the slightest noise, nothing

brighter than a 50 Watt lamp; only a rather complicated system of glass tubing and some measuring instruments, looking much as they have looked any time in the past twenty years, and yet from that table have come the following things: first, the Mazda C lamp, which annually saves the public many millions in its lighting bills, makes workshops and streets brighter and safer, adds to the beauty of homes and public buildings, makes motoring safer at night, and adds to comfort and convenience in many ways; next the high-vacuum power tube, the heart of the broadcasting station, and the device which created broadcasting—even as the microphone created telephony—and thereby gave the public a great new source of entertainment, education and convenience; next, the thoriated filament, which gave to radio receiving tubes a much higher efficiency; and finally atomic-hydrogen welding, the commercial exploitation of which has only begun so that its potentialities in producing new and better structures and new and better structural technique can only be guessed. If the story of that table could be fully told, from the initial experiments to the discovery of new scientific truths, and, through the developments based on these new facts to the ultimate benefits to the public, a true and striking presentation would

be made of the methods and results of industrial research."

Some may recognize that table as the work bench of Irving Langmuir, the latest American Nobel prize winner in chemistry.

Thanks to it and to other tables like it, we live in a period of rich accomplishment, a period in which the common man is privileged to enjoy an ease of living denied to the monarch of yesterday. It is fitting that the Chicago Exposition of 1933, designed to depict a century of progress, should have been dedicated to "the dependence of industry on scientific research."

The words provide a thrill, and provoke reflection: The dependence of *industry* on *scientific* research! At once an understatement and a warning. But of this later. Let us go back to the beginnings of research.

CHAPTER II

THE LONG CLIMB TO FREEDOM OF THOUGHT

THERE is a ratchet in the machinery of progress that holds the upward lift of one generation for the beginning of the next. It is true of the slow processes of evolution and of man's progress through purposeful achievement. The former appears to characterize the trend of all living things; the latter began to differentiate man, when and to the degree that he became *Homo sapiens*.

For generations on end, man's material progress was slow. It increased with the development of speech, and of written characters that gave language permanence. It increased with the invention of those building blocks for word formation that we call the alphabet, with the invention of paper, and, above all, with the invention of printing with movable type—all serving the end that knowledge, which is not biologically inheritable, should become the legacy of each generation to the next.

Insight into Nature's ways came slowly, but

not because of lack of mental power; the mental capacity of present-day man is not appreciably greater than that of the man of earliest history; evolution's processes are slow. Progress depended rather on a viewpoint and a method, and grew apace only as this viewpoint and this method gained general acceptance. We call them the modern, scientific viewpoint and method, the viewpoint and method of research. Still they are modern mainly in the fact of their general acceptance. They gained general acceptance as they were able to demonstrate their practical value.

We do not know just how early, but here and there, in point of time and place, men have gone to Nature with open minds, and studied her ways first hand. We do know that certain of the early Greeks, notably Thales, Pythagoras, and Archimedes, experimentally determined facts that have stood the test of time. Yet there is evidence of considerable progress in the arts long before their time. The Egyptians developed enough geometry to enable them to re-establish land boundaries obliterated by the overflowing Nile. The Phoenicians were interested in numbers to an extent that might be helpful in trade. It remained for the Greeks to develop these small beginnings into systems of mathematics; unlike the others, they were interested in mathematical science for

its own sake. Aristotle, who applied himself to all learning may perhaps be excused for having been interested more in the classification than the establishment of facts. Among Greek physicians, Hippocrates and Galen set what was for their time a high standard in direct observation and freedom from the prevailing mysticism.

In power of observation, mathematical ability, and mechanical ingenuity the ancients were not lacking. Nor did they lack imagination or industry. Seemingly the world was ready to continue the scientific progress begun by them. But with the fall of Greece, science marked time for more than a thousand years. Men looked to authority for their facts, not to Nature at first hand. They thought to gain knowledge by pure deduction from accepted dogma. There was no lack of logical power, only a lack of sound premises; the truth had been revealed, the book closed. Finally, with the crusades, ignorance and provincialism began to give way. In the fifteenth century, progress gained momentum with the invention of movable-type printing, and the discovery of the new world. With the fall of Constantinople the Greek and Roman classics began filtering into Europe from Arabia, and the growing world commerce and colonization further broadened the outlook.

But even before this there arose one outstanding in his vision of science, namely, that English friar of the thirteenth century, Roger Bacon. He went to Paris and is believed to have had access to the writings of the Arabian philosophers who during the dark centuries had preserved and cultivated a knowledge of the classics. Bacon was the first European to emphasize the importance of experiment as the only reliable source of facts concerning natural phenomena. As a "reward" he was forced to spend the last thirteen years of his life in prison. Late in the fifteenth century, Leonardo da Vinci, Italian engineer, architect, sculptor, painter, and a genius in all, showed a keen appreciation of the value and future possibilities of the open mind and direct appeal to Nature; but this waited for two hundred years to be discovered. Early in the sixteenth century we find one, Paracelsus, Swiss alchemist and physician, practicing medicine, and bidding defiance to those who after more than 1300 years were blindly following Galen. Paracelsus taught "that the activities of the human body are chemical, that health depends on the proper chemical composition of the organs and fluids, and that the object of chemistry is to prepare medicines." Persecution was the lot of this physician who dared to do his own thinking. About this

same time Copernicus, Polish doctor-priest, who interested himself in astronomy, acquired the conviction that the earth and planets revolved about the sun, not the sun, planets and stars about the earth, as Ptolemy had taught and as was currently believed. But he discreetly waited until he was on his death bed before publishing his views. A hundred years later Tycho Brahe, a Dane, set himself the task of charting the heavens. His work was a model of painstaking accuracy, and provided data of great value to navigation. From his carefully observed and recorded facts, his German student-assistant, Kepler, was able to formulate important laws governing the movements of the planets. These laws appear to have been too mathematical to be objectionable to his contemporaries. Galileo, Italian astronomer, followed, observing with the aid of a telescope of his own construction that Mercury and Venus have their phases like our Moon, as would be expected from the Copernican theory. Also, he not only questioned but proved to be false Aristotle's authoritative pronouncement that the velocities of falling bodies are proportional to their weights. He was brought before the Inquisition and spent his later years under guard.

The year Galileo died (1642) was born one less out of step with his time, Isaac Newton;

but this was because people had become somewhat more tolerant. He invented the reflecting telescope, resolved white light into its primary colors, demonstrated the law of gravitation and devised a system of mathematics to help him do it. Yet even he wrote: "I see a man must either resolve to put out nothing new or become a slave to defend it."

These leaders of thought, like our modern workers in the field of pure science, were actuated by a desire to seek the truth without thought of personal gain. Progress was being made, though slowly. The greatest gain, a gradual one, was in freedom of thought.

Meanwhile, not only were men observing; they were also experimenting, though, at first, not for the pure love of it.

CHAPTER III

FROM DARKNESS INTO DAWN

WHILE all scientific progress has been beholden to disinterested work in the domain of pure science, chemistry's beginning was not of this sort. To become a science it had to change its ways. The alchemist, who was the forerunner of the chemist, sought as his objective the transmutation of baser metals into gold, and the indefinite prolongation of life. While there were rogues among them the many must have been honest, for they worked hard and enthusiastically. They were prototypes of our modern scientific researchers, with this all-important difference: they were not seeking knowledge as much as personal gain.

Alchemy was practiced all during the Middle Ages, and began to flourish as feudalism waned and monarchy waxed in power and need of liquid wealth. In spite of a violent disposition to break with accepted teachings, Paracelsus seems to have had much confidence in alchemy, but he influenced it in the direction of making medicines rather than gold. Out of this came some use-

ful information concerning both medicines and poisons, as out of the effort to make gold came, as by-products, new chemicals and empirical knowledge of later value to the science of chemistry.

The first to break away from the old order was Robert Boyle, son of the Earl of Cork, and a contemporary of Newton. Boyle was the first to have a fairly clear concept of "element," "compound" and "mixture." He discovered and formulated the relation of pressure and volume in gases. He was an enthusiastic experimenter, and what is more important, he insisted that science should be pursued for its own sake. The true scientist is at heart an amateur. Boyle was an amateur and could afford to be. His work marked the beginning of chemical research in the modern sense.

But Boyle was ahead of his time. Alchemy's influence lingered. From earth, water, air and fire, the basic principles of Aristotle, to the vastly clearer concept of Boyle was too great a step for the many. A fantastic concept gained general acceptance and retarded progress for a century. An attempt was made to explain the mystery of combustion by assuming the existence of a principle called phlogiston, the possession of which made things combustible, and the escape of which

accompanied the phenomenon of combustion. It proved to be not in harmony with all of the facts, but, once accepted, it died hard.

Belief in the possibility of changing baser metals into gold lingered until late in the eighteenth century, when one James Price, Fellow of the Royal Society, seems possibly to have deceived himself as well as many others, into believing that he really had the secret. He convinced a select group of men of rank, who witnessed his experiments, that his claims were true, and the King himself was pleased to receive a specimen of the new gold. But Price was called upon to prove his claims before his fellow members of the Society. Repairing to his laboratory he remained secluded for six months. When his associates were finally invited to witness the test, he drank a deadly potion and expired before their eyes. From then on interest in alchemy languished in England, and finally died out everywhere, only to be revived in our day, but in a very different way.

Meanwhile, painstaking experimenting was also being done for the pure love of it. Joseph Black in Scotland did important work with gases. He seems to have been the first to distinguish between heat and temperature. He discovered specific heat and latent heat and determined them for

water and steam. Cavendish, eccentric Englishman of wealth, discovered hydrogen, which he surmised might be pure phlogiston. He exploded a mixture of it with air thereby obtaining water. Also he "fixed" atmospheric nitrogen by passing sparks through air.

An English schoolmaster, John Dalton, put forth his atomic theory to explain the fact that elements always combine in definite proportions, and began determining their relative combining weights. Berzelius, in Sweden, tireless and painstaking, worked with surprising accuracy on the determination of these weights, and devised more convenient chemical symbols. Gay-Lussac, in France, and Avagadro, in Italy, propounded generalizations that made clear the distinction between "atom" and "molecule," and put new meaning into "atomic weight," but their full import waited fifty years to be understood. Earlier, Scheele, Swedish apothecary, had found time to discover the gases, chlorine and oxygen. Failure to publish caused the discovery of the last-named to be credited to another, though neither recognized its rôle in combustion. This other experimenter was Joseph Priestley, English non-conformist preacher and amateur in science. He acquired an interest in the subject of electricity through acquaintance with Benjamin Franklin

whom he met in London. From this he turned his attention to chemistry, which as we see it to-day, was not as great a step as it might have appeared to be. He had been experimenting with gases, quite the fashion at the time, when one day by means of a large sun glass he heated what we now know as mercuric oxide. Metallic mercury was formed and a gas given off which he collected in a bottle. A lighted candle was standing nearby. Seizing it he thrust the flame into the gas. To his delight instead of putting out the flame, as did the gas that he had one time collected over a beer vat, the new gas caused the flame to burn with greatly increased vigor. To his amazement even a red hot iron wire sputtered until consumed. His discovery contained the germ of the modern science of chemistry, but he did not know it.

In Paris was Antoine Laurent Lavoisier, young man of wealth and an indefatigable experimenter, who was trying to solve the secret of combustion. He was firm in the conviction that "one may take it for granted that in every reaction there is an equal quantity of matter before and after the operation." It was a new doctrine. To him, in 1774, Priestley described his work on the gas from mercuric oxide. Lavoisier repeated the experiment. With the aid of a delicate balance

he proved that the weight of the gas expelled was just equal to the loss of weight of the mercuric oxide. He called the new gas "oxygen." From this and other experiments the nature of combustion became clear. Chemistry was at last headed in the right direction. Ever since and with rapid pace it has been passing on to new conquests.

In 1794, as he was extending to the human body his researches in combustion, Lavoisier was called before the Revolutionary Tribunal to answer to a charge of unfriendliness toward the cause of the French Revolutionists; his life was ended on the guillotine. "It took but a moment to cut off that head, though a hundred years perhaps will be required to produce another like it," was the comment of Lagrange, French mathematician. The same year Priestley left England for the new United States of America to escape persecution for his outspoken friendliness toward the same political cause.

Other workers carried on, discovering facts and formulating laws of great value in the furtherance of chemical science. In 1828, Woehler, a student of Berzelius, prepared metallic aluminum, and the same year performed a miracle, in that he made in the laboratory an organic compound, urea. Thus another of chemistry's shackles was

cast off. Up to that time organic compounds were believed to be the products of vital processes only, that is, the products of plant or animal organs, therefore, "organic." Liebig, co-worker with Woehler, devised methods for the analysis of such compounds; and the great field of organic chemical discovery, and of synthesis, was open for cultivation. To-day the number of organic compounds that have been studied is fast approaching the half million mark; and there is no end in sight.

Meanwhile progress was being made in another field of great importance. William Gilbert, in England, physician to the Court of Elizabeth began as a hobby the study of the magnetic properties of lodestone and the time-honored experiment of rubbing amber and causing it to pick up pith balls and other light objects. For the first time he pointed out that these were two different phenomena. Also, he contended that the earth is a magnet and that it accounts for the behavior of the compass. Others followed, including our own Benjamin Franklin, who identified the new electric phenomena as mild forms of lightning, and who first suggested the terms *positive* and *negative* to describe the two types of phenomena observed, though as we now view it they would better be turned about.

As the century was drawing to a close, Volta, professor of physics in Italy, was putting some meaning into the phenomenon of "jerking frog's legs" that Galvani had observed but had not explained. Volta invented the electric cell, a first step toward bringing dynamic electricity to the service of chemistry, as well as new possibilities to the growing science of electricity. Davy, in England, employing a current from a battery of Volta's cells, separated metallic potassium from molten potash. Oersted, in Denmark, discovered that a current passing through a conductor develops a magnetic field, and Ampere and Coulomb, in France, and Ohm, in Germany, formulated laws helpful to further study and use of the new form of energy. Then, most important of all to our century of progress, Faraday, in England, discovered electromagnetic induction, by which electricity can be transformed into mechanical power, or mechanical power into electricity. This was in 1831.

Important is it also to record that a century and a half earlier a Dutch linen draper, Anton van Leeuwenhoek, polished lenses as a pastime and with them was delighted to see minute forms of life that never before had been revealed.

Thus step by step was progress made; slowly at first but with increasing pace as new knowledge

came to light the way. Intuitively it came to be felt that perpetual change is the order of Nature, and that it is ours to hasten it and direct it as fits our need. It was break of day for a better understanding of matter and energy.

But let us turn back to the middle of the seventeen hundreds. There is work going on in England that is of neither the heavens nor the laboratory, but is destined to be of tremendous importance to civilization in many ways, including the opportunity to put to practical use our growing understanding of Nature.

CHAPTER IV

ENSLAVING THE INANIMATE

THE county of Lancashire, in England, was the home of spinning and weaving. By the sea and damp, it was about right in humidity to give the necessary suppleness to the textile fibers. Carding, spinning, and weaving had long been an industry of the household. The head of the family did the weaving and the rest of the family did the carding and spinning. Cultivation of a small plot of ground supplemented the meager returns from the work in the home. The demand was for more spinners or faster spinning, and this demand was doubled when, in 1733, hand weaving was speeded up by the invention of the fly shuttle.

Though the weaver worked in his own home he did not sell his own product. He was a subcontractor working for a general contractor. This was an outgrowth of the mercantile system that had been in vogue throughout Europe since the days of Henry VIII. The demand was for increased production of manufactures to improve the trade balance, that is, increase the

stock of gold and silver in the national treasury. Each nation was trying to do all the manufacturing and to induce other nations to supply only needed raw materials. As for England, the plan worked to perfection for a time in trade with her own colonies, especially after Cromwell had wrested from the Dutch by war and treaty the English colonial carrying trade. International competition was strong, and surveillance of industry made for unrest. When to meet growing government costs, new taxes began to be imposed both at home and in the colonies, restlessness increased. Over here restlessness found expression in a certain "tea party" in Boston harbor which led to political happenings of world-wide importance. In England, it found expression in labor-saving invention and group-production which have since revolutionized civilization itself.

It all started with James Hargraves and his "spinning jenny." Jenny was the name of his daughter who with the new machine was able to keep eight spindles going instead of one. The need had been for more spinners, but not for eight times as many. Instead of buying Hargraves' new machines to increase their own output, a mob of those threatened with "technological unemployment" broke into Hargraves' home

and wrecked his new machine. But ideas are not so easily destroyed.

Now enters Richard Arkwright, barber and hair dresser, who had an eye to business rather than invention. He made wigs and went about seeking heads of hair from the weavers' wives and daughters. This brought him into touch with conditions and he saw the opportunities for mechanical spinning. He induced a clock maker who had ideas on the subject to design for him a spinning device. It worked better than Hargraves' spinning jenny in that it could make out of cotton not only weft yarns, but also warp yarns, which needed to be much stronger. Formerly linen alone could be used for warp. He took out a patent in his own name and proceeded to set up a mill for spinning. But the home weavers would have none of his mill-made yarn so he had to introduce looms into his mill and do his own weaving. This gave him control of the whole process of producing cotton fabrics.

What Arkwright lacked in mechanical ability he made up for in managing ability. He turned the whole factory into a machine. He and all England grew in wealth and power. He was eventually knighted. England's production of cotton goods increased several fold, as spindle and loom moved from home to mill.

The limiting factor was now the production of cotton. Our own southern planters were supplying a little cotton to the English mills. A slave in one day could separate from the seeds by hand only a pound or two of cotton wool a day. They could not compete with the planters in the West Indies whose cotton was of longer fiber and more easily separated. Now rare opportunity for invention existed over here. Eli Whitney, of Massachusetts, just graduated from Yale and visiting in Savannah, saw it. His cotton engine, or cotton gin, for short, patented in 1794, brought small returns to Whitney, but increased the production of England's looms, lowered the price of cotton goods, made human slavery more profitable, and created a political problem in America that was to be fought out between the North and the South a few generations later.

The year Arkwright received a patent on a spinning "frame," James Watt, "mathematical-instrument maker to the University of Glasgow" was granted a patent on a steam engine. This was in 1769. The tradition that it all came to him while playing with a tea kettle better portrays his native bent than the origin of his steam engine. There were steam engines before Watt's but the best of them, one invented by Thomas Newcomen in 1738, was clumsy and wasteful of

fuel. Working with the collaboration of Professor Black, lecturer in Chemistry, who had just discovered the facts about the specific heat and latent heat of steam, Watt produced an engine of greatly increased efficiency, one that did four times as much work as Newcomen's with a given amount of fuel; he later added one improvement after another to the mechanism. Newcomen's cylinder was closed at one end only; the steam was condensed in the cylinder and air pressure pushed back the piston. Newcomen's engine was little or no more economical than man power. Watt employed an outside condenser, and finally a cylinder closed at both ends. Later he cut off the steam before the stroke was complete and let it expand in the cylinder. His most important achievement was that of increasing the efficiency. But Newcomen was a blacksmith and did not have the advantage of coöperation with a researching professor who had learned the hidden ways of steam.

Watt was versatile as well as ingenious. He enjoyed the acquaintance of Bertholet, in Paris, chemist and member of the Academy of Sciences. Bertholet told him of his experiments with chlorine, which had been discovered by the Swedish chemist, Scheele, and how he, Bertholet, had found it quickly bleached the color out of

vegetable fibers. Back in Scotland, Watt worked out the conditions in a practical way. And so it was that Watt finally came to supply the power for the new textile mills and the method of bleaching their yarn, both of which formerly had been laborious, time-consuming, and otherwise unsatisfactory.

Watt continued to perfect his engine, which soon replaced Newcomen's in pumping water at the mines, and began to be adopted generally. Fulton, American portrait painter, used it in his "Clermont," which in 1807 made its successful trip up the Hudson from New York to Clermont, home of Chancellor Livingston, his financial backer; and Stephenson in England used it in his "Rocket" that, in 1829, ran on rails and pulled carriages. Engineers of the day prophesied failure for Stephenson. And Napoleon said of Fulton that a crazy Yankee tried to make him believe he could sail a ship without sails. Therein lies the reason why Fulton steamed up the Hudson instead of the Seine. He had tried to interest the French after getting no backing at home. But Livingston was Minister to France at the time and became interested in backing him personally over here.

All praise to our Hargraveses, Arkwrights, Watts, Fultons, and Stephensons! No, not all

the praise. Let us not forget our Priestleys, Lavoisiers, Blacks, Scheeles, and Bertholets. Without them we should still be puttering along with old materials.

As a result of this substitution of inanimate for animate power and dexterity England has begun to amass great wealth. How is it in the United States of America? It was in the seventh year of our independence that Priestley found with us a haven of refuge. Let us follow him over and look about.

CHAPTER V

EARLY DAYS IN THE NEW REPUBLIC

IT IS June, 1794. After two months at sea, the exile, Priestley, reaches New York and is received by a delegation of welcome headed by Governor George Clinton. Also represented is "a numerous body of freemen who associate to cultivate the love of liberty," and who are known as the Tammany Society of New York. The welcoming ceremony ended, Priestley proceeds to Northumberland, Pennsylvania, where he is destined to spend his ten remaining years with his three sons who had preceded him to America.

Priestley's friend, Benjamin Franklin, was not among those extending a welcome. Franklin had been sleeping beneath a marble slab in the shadow of the "Cradle of Liberty" since 1790, the first year of Washington's administration; also the year of the first patent act, which provided for an examining board consisting of the Secretary of State, the Secretary of War, and the Attorney General, or any two of them.

Holland Thompson in *The Age of Invention*, a

volume of *The Chronicles of America*, published by the Yale University Press, thus vividly describes conditions:

"In the year, 1790, was taken the First Census of the United States. The new nation had a population of about four million people. It then included practically the present territory east of the Mississippi, except the Floridas, which belonged to Spain. But only a small part of this territory was occupied. Much of New York and Pennsylvania was savage wilderness. Only the seacoast of Maine was inhabited, and the eighty-two thousand inhabitants of Georgia hugged the Savannah River. Hardy pioneers had climbed the Alleghenies into Kentucky and Tennessee, but the Northwest Territory—comprising Ohio, Michigan, Indiana, Illinois, and Wisconsin—was not enumerated at all, so scanty were its people, perhaps not more than four thousand.

"Though the First Census did not classify the population by occupation it is certain that nine-tenths of the breadwinners worked more or less upon the soil. The remaining tenth were engaged in trade, transportation, manufacturing, fishing, and included also the professional men, doctors, lawyers, clergymen, teachers, and the like. In other words, nine out of ten of the population were engaged primarily in the production

of food, an occupation which to-day engages less than three out of ten. This comparison, however, requires some qualification. The farmer and the farmer's wife and children performed many tasks which are now done in factories. The successful farmer on the frontier had to be a jack of many trades. Often he tanned leather and made shoes for his family and harness for his horses. He was carpenter, blacksmith, cobbler, and often boat-builder and fisherman as well. His wife made soap and candles, spun yarn and dyed it, wove cloth and made the clothes the family wore, to mention only a few of the tasks of the women of the eighteenth century.

"The organization of industry, however, was beginning. Here and there were small paper mills, glass factories—though many houses in the back country were without glass windows—potteries, and iron foundries and forges. Capitalists, in some places, had brought together a few handloom weavers to make cloth for sale, and the famous shoemakers of Massachusetts commonly worked in groups.

"The mineral resources of the United States were practically unknown. The country seems to have produced iron enough for its simple needs, some coal, copper, lead, gold, silver, and sulphur. But we may say that mining was hardly practiced at all.

"The fisheries and the shipyards were great sources of wealth, especially for New England. The cod fishers numbered several hundred vessels and the whalers about forty. Thousands of citizens living along the seashore and the rivers fished more or less to add to the local food supply. The deep-sea fishermen exported a part of their catch, dried and salted. Yankee vessels sailed to all ports of the world and carried the greater part of the foreign commerce of the United States. Flour, tobacco, rice, wheat, corn, dried fish, potash, indigo, and staves were the principal exports. Great Britain was the best customer, with the French West Indies next, and then the British West Indies. The principal imports came from the same countries. Imports and exports practically balanced each other, at about twenty million dollars annually, or about five dollars a head. The great merchants owned ships and many of them, such as John Hancock of Boston, and Stephen Girard of Philadelphia, had grown very rich.

"Inland transportation depended on horses and oxen or boats. There were few good roads, sometimes none at all save bridle paths and trails. The settlers along the river valleys used boats almost entirely. Stagecoaches made the journey from New York to Boston in four days

in summer and in six in winter. Two days were required to go between New York and Philadelphia. Forty to fifty miles a day was the speed of the best coaches, provided always that they did not tumble into the ditch. In many parts of the country one must needs travel on horseback or on foot.

"Even the wealthiest Americans of those days had few or none of the articles which we regard to-day as necessities of life. The houses were provided with open fires—which, however cheerful, did not keep them warm—or else with Franklin stoves. To strike a fire one must have the flint and tinder box, for matches were unknown until about 1830. Candles made the darkness visible. There was neither plumbing nor running water. Food was cooked in the ashes or over an open fire.

"The farmer's tools were no less crude than his wife's. His plough had been little improved since the days of Rameses. He sowed his wheat by hand, cut it with a sickle, flailed it out upon the floor, and laboriously winnowed away the chaff."

It may be added that food was plentiful, but during the winter, particularly in the North, was much restricted in variety. The "canning" of fruit was not introduced until later. The poor

man's family gathered about the light of one candle; the well-to-do showed their affluence by burning groups of candles in pewter candelabra. The rich might preserve the likenesses of their loved ones by employing a portrait painter; the poor held them in memory; photography had not been invented. Surgical operations, when performed, were rather gruesome ordeals; neither rich nor poor had as yet the benefit of aseptic surgery or anaesthesia. Appendicitis was "inflammation of the bowels;" one got well, or one did not. Smallpox vaccine had not yet been discovered. An epidemic of this dread disease, or of yellow fever which occasionally came up from the West Indies, was escaped from, if possible, not controlled. Mortality from diphtheria and typhoid was very high. The knowledge that there was a causal connection between germs and disease came much later.

The mechanical revolution had made little impression on America, except to bring a small measure of prosperity to the southern planter. This prosperity increased rapidly, however, with the introduction of the cotton gin. England adhered to a policy of keeping manufacturing at home. Plans of her textile machinery were carefully guarded and were not allowed to leave the country.

But the success of Jenner's smallpox vaccine,

discovered in 1796, was so pronounced that it was introduced into America in 1800. The same year Davy discovered the anaesthetic value of "laughing gas" but it was the middle of the century before the anaesthetic value of chloroform and of ether was discovered. In America, up to 1833, enslavement of the inanimate was still confined largely to wind and water.

But steam was beginning to work its wonders. That year the *Royal William* steamed across the Atlantic, and four years later the *Great Western*, the first steamship especially designed for ocean travel, was built in England. Yet the railway tarried. Oliver Evans of Philadelphia, and John Stevens of Hoboken built and ran steam locomotives. The latter tried to get a railroad built instead of the Erie Canal. His proposal was rejected by the canal commissioners who did not believe the construction of a road bed would be feasible to "sustain so heavy a weight as you propose moving at the rate of four miles an hour on wheels." Then the war of 1812 came and further retarded development. The Erie Canal was completed in 1825. Steamboats were plying the larger rivers, when not frozen over, but land travel was by horses, mules, and oxen. Few then dreamed of travelling by steam on land.

With such an inheritance we enter our Century of Progress.

CHAPTER VI

GENIUS UNFETTERED AT HOME AND ABROAD

With respect to native endowment, all men are not created equal. But the genius, born of palace or hovel, should be free to exercise his God-given right of expression. This freedom was the past century's greatest gift to civilization.

It came with education of the masses. As to how that came there is difference of opinion. It has been credited to democracy. It was, perhaps, a corollary of democracy. But the Pilgrim Fathers established schools for all as soon as they landed on American shores, and were the first to make education compulsory. There were no castes among them, and besides they wanted the faithful to be able to read the word on whose authority their faith was founded. Then again, with the coming of mechanical power, which was cheaper than man power even at a mere subsistence wage, intelligence began to command a premium. Men were wanted to design and build engines and machines, and many more were

wanted to tend them. The mass of the people did not longer have to be kept ignorant to maintain the supply of willing brute force. Work could be better performed by an engine-driven machine in the hands of an intelligent attendant. While men were constantly being thrown out of employment as the machine invaded one industry after another, the over-all result was a greater number employed, a higher wage, and better living at a relatively lower cost. The illiterate laborer's son went to school, and, more and more frequently, as time went on, he went to "college." The acceleration that regularly characterizes progress through creative thought was multiplied because of a large increase in the number of capable thinkers. Not a few of "the rude forefathers of the hamlet" of Thomas Gray's century passed life on to those privileged during this past century of progress "to scatter plenty o'er a smiling land, and read their history in a nation's eyes" . . .

In England, home of the mechanical and industrial revolutions, education continued an institution of the church, or was had at personal expense. It was therefore a practical monopoly of the privileged classes. Gentlemen were being educated for political or religious leadership. Emphasis was placed upon the classics with

relatively little thought of the great forces that England had been the first to turn loose.

In France, so far as education of the masses was concerned, much the same sentiment existed. Even Rousseau, whose writings are credited with having been a factor in bringing about the Revolution, held the common man to be in no need of schooling. Following the Revolution, there was too much of military victory to permit a great deal of thought to be given to education of the masses.

But not so with the vanquished. The Germans, after their crushing defeat at the hands of Napoleon in 1806, followed American precedent by establishing state education for all the people, but, unlike America, they early began to emphasize science, particularly that basic science, chemistry. There was logic in this emphasis, since theirs was an old domain of limited natural resources. The inevitable day came when aspiring youth from England, France, and America went to sit at the feet of Germany's wise men of science. Inevitably there came also, in the latter part of the century and up to the beginning of the world war, industrial leadership for Germany in what has been styled "laboratory advance," though in mechanical advance they owed much to the United States.

Of course, progress was going on elsewhere, and education was advancing. We, in the United States, affording opportunity to all, were primarily engaged in the subjugation of a vast new territory of apparently unlimited resources. We had our able men of science, but science was not our immediate problem. Our dominant industry was agriculture. To its aid came McCormick with his reaper, establishing at Chicago in 1847, a great manufacturing industry. Others followed and American-made agricultural machines inaugurated an agricultural revolution which eventually spread into practically every country of the Globe. The industry received a great impetus during the Civil War and became a potent factor in the success of the armies of the North, made up in large measure, as they were, of men from the farms. With the aid of agricultural machinery those left behind were able not only to feed the army and the folks at home but to export much wheat to Europe.

Mechanical spinning and weaving had begun in New England with the War of 1812, and had developed into an efficient industry. But sewing was still done by hand and called forth further invention. In 1846, after much personal hardship, Elias Howe received a patent on his sewing machine; in the eighties the sewing machine agent was seen everywhere in the land.

Our distances were great and the development of a vast inland territory awaited better transportation. The period from 1840 to 1860 was one of rapid railway development. The mechanical revolution was taking hold over here in earnest. A new spirit was abroad making itself felt in many ways. During this period the Smithsonian Institution and the American Association for the Advancement of Science were founded. This period is sometimes referred to as "The Epoch of 1840."

It is fitting that during this period those historic words: *What hath God wrought!* should have been transmitted miles in a flash by that new wonder, the telegraph. Inspired by an experiment performed by Joseph Henry, its practical realization was had only after great personal sacrifice by that inventing Professor of Fine Arts, Samuel F. B. Morse.

It was during this period that Goodyear discovered the vulcanization of rubber, the happy culmination of well-nigh religious zeal and ten years of martyrdom, including imprisonment for debt.

Then after the Civil War, in 1876, came Bell and his telephone, destined still further to economize time and thereby greatly facilitate commerce and industry everywhere.

The same year a handful of chemists founded the American Chemical Society, since grown to eighteen thousand members. Its founding had been suggested two years earlier during the pilgrimage of a small group to Priestley's grave in Northumberland to commemorate the hundredth anniversary of the discovery of oxygen.

That year the Centennial Exposition afforded us an opportunity to check our own progress in the arts against that made by Europe. The comparison showed greater attention given abroad to refinement of detail, but on the whole, it was encouraging.

Still the generation that returned to its kerosene lamps, horse-drawn vehicles, and roads that gave a choice of dust or mud, well pleased with the unprecedented progress it enjoyed, had much in waiting to enlighten and enliven that was just around the corner. For soon came Edison with his carbon-filament electric lamp and his power stations that brought electricity to the nation and to the world; also Tesla with his alternating current to cheapen distribution and his induction motor to provide power as well as light. Edison had already amazed and delighted us with his phonograph; then followed it in a few years with his moving picture machine.

Before 1890 the continent had been spanned by

five separate railroads. Pullman had added greater comfort and Westinghouse greater safety in travel. To these and to industry in general the Englishman, Bessemer, and the American, Kelly, with their air-blown steel had contributed greatly, though later this was largely superseded by the open hearth process, successfully employing high-phosphorus ores.

Again it became time to take stock of progress. In 1893 was held the great Columbian Exposition. Thither the Nation foregathered to marvel at the rapid climb of material progress. Deep down in the hearts of those who attended was the feeling that a plateau of stabilized realization lay ahead. Certainly this rapid pace could not be maintained! What was there left to invent?

Nevertheless with a return to prosperity came accelerated progress. There was great extension of electric power. It was supplied for homes, factories, and electric traction. The steam turbine came linked arm in arm with the electric generator to provide a compact unit of increased efficiency and unheard-of capacity. Niagara was harnessed to provide an abundance of cheap electric power. Pupin brought us the long-distance telephone. Frasch made us independent of foreign sources for our sulphur by his bold and ingenious process of melting and blowing it out

of the bowels of the earth with superheated steam. Portland cement had already joined steel in a most happy union of reinforcing service for edifice and highway. The automobile came with its internal combustion engine, utilizing the volatile petroleum distillate which the law had barred from the kerosene that still provided light for no small part of the nation. At first a "horseless carriage," soon it acquired originality and began to remake the whole country. The Wrights, adding skill to Langley's proved principles of design, succeeded in conquering flight with a heavier-than-air machine. Wireless came to us from over seas, but DeForest turned it into radio, which later burst upon us over night.

Then there were Hyatt and his new plastic, "Celluloid;" Hall and his electrolytic process for aluminum; Castner and his electrolytic process for caustic soda, chlorine and hydrogen; Acheson and his new synthetic abrasive, "Carborundum;" Baekeland and his new synthetic resin, "Bakelite;" Willson and his calcium carbide; Taylor and White, and their high-speed machining tools of alloy steel—all these we shall have occasion to refer to later. Then, just as the world went to war, Edison's faithful lamp filament of carbon began to give place to the new and much more efficient tungsten filament, developed by Coolidge, work-

ing as part of a comparatively new agency in discovery and invention, namely, organized research.

There was earlier research back of all these achievements and some brilliant research done by those who achieved. In fact research was of vital importance to undertakings thought to be related to it in none but the most remote and negligible way. One such case was that of the Panama Canal. It appears reasonably certain that our engineers were saved from defeat, such as befell DeLesseps, by a bit of research conducted by Reed and his brave medical collaborators, who established a causal connection between the bite of a certain type of mosquito and the incidence of yellow fever. The application of this new knowledge gave to that canal region of pestilence a lower death rate than was experienced at home.

And not alone in our industries, our canal digging, and our health, were we profoundly influenced by research, but also in our politics. Even as gloriously eloquent reference to a crown of thorns and a cross of gold was being made in Chicago's Convention Hall, two metallurgical chemists, MacArthur and Forrest, working in South Africa had perfected and for six years had been employing their new cyanide process of gold extraction. This applied to otherwise unworkable ore slimes and tailings had begun to add sig-

nificantly to the world's gold supply. In two more years the annual production had been doubled and was continuing upward. Prices began to rise, the lot of the debtor, which had grown steadily worse since the Civil War, through falling gold production, began to improve, and the free silver movement began to lose its force. The advocates of sound money were reassured; though probably few knew just how it all came about until told in interesting detail a quarter of a century later by Mark Sullivan in his *Our Times, The Turn of the Century.*

But research had been conducted abroad that did not work for our benefit. Although at the outbreak of hostilities in 1914, we had 1,200,000 motor cars, which was twice as many as in all the rest of the world; although our manufactured products had reached a value of $24,000,000,000 with 8,300,000 persons employed, as compared with $2,000,000,000 and 1,300,000 employed, in 1860; although the value added to raw materials had been doubled, as had also wages; although we led in general mechanical advance, in the application of electricity to chemical processes, and in the production of heavy chemicals, still we had been content to depend largely on foreign sources, mainly Germany, for our supply of synthetic organic medicines and dyes; this in spite of the

fact that these medicines included a few of great importance in the treatment of disease, and that these dyes had become indispensable to industries whose aggregate output was valued at two and a half billion dollars and whose employees numbered a million people. When, later, importation of these materials was shut off by war blockade, we began to awaken to their importance. Important they were indeed, though their tonnage was small and their money value only about one per cent of the value of the products of the industries that became well-nigh helpless without them.

That a million men would "spring to arms" in defence of the nation was a true statement of their spirit only. We might be able to provide the arms; could we provide the ammunition? This was another problem. "T.N.T." was the great need, but where was the toluene to be had from which to prepare it? It was escaping, and had been for years, as part of the smoke from our "bee hive" coke ovens, just as had the other coal-tar products needed for synthetic dyes.

Then we began to build "by-product" coke ovens to save the smoke. There was a chemical awakening in every needed line. Our War Department, after first finding "no need for chemistry," came with the rest of the country, to recognize that the need of up-to-date explosives,

smoke screens, fuels, war gases, antiseptics, anaesthetics; also the many special materials—alloys, plastics, coatings—needed by the industries back of the fighting men, made modern warfare basically chemical.

Having awakened to the fact that we were woefully unprepared to compete successfully in warfare, when peace again had come we remained awake to realize that we had been equally unprepared to compete in a new world of industry. We determined to become and to remain self-contained with respect to those key products, dyes and other "organic synthetics," whose peace-time production represents a large measure of preparedness for war.

On the other side of the struggle is to be found an interesting contrast in preparedness. Those who had long led in "laboratory advance," had, before the precipitation of hostilities, taken care that they should not lack "fixed nitrogen" in the event that the world's only large store of it, namely, Chili saltpeter, should become unavailable. Whether or not the fact is significant, as early as 1913 Haber had produced ammonia by the direct union of nitrogen and hydrogen, and Ostwald had developed a method for its direct oxidation to the nitric acid needed in explosives and in agriculture. It has been stated that with-

out this laboratory advance Germany would have been forced to sue for peace two or three years earlier than she did.

We have learned our lesson, and are now assuming leadership in the endless domain of science, just as once we led in the exploitation of what at the time seemed an endless domain of undeveloped natural resources.

We shall return to the subject of material progress, but back of it all—back of our more-than-creditable free-lancing in discovery and invention, back of the better utilization of natural resources—has been new knowledge gained without thought of material reward.

CHAPTER VII

DEEPER UNDERSTANDING, GREATER POWER[1]

SCIENCE is the father of progress; "natural philosophy" was its grandfather. In 1833 science was already a healthy infant but its future multitudinous offspring were unsuspected. The study of nature for its own sake had been the leisurely pursuit of wealthy men like Lavoisier and Cavendish and of clergymen like Priestley. Now it became a profession. The colleges had added natural philosophy to moral philosophy and theology which so long had dominated their faculties. The effort to understand God through the study of His works became respectable, and almost imperceptibly science came of age. Then by the middle of the century natural philosophy gave way to the powerful specialized sciences,—chemistry, the science of matter; physics, the science of energy; biology,

[1] We are indebted to Dr. Gerald Wendt, editor of *Chemical Reviews*, for this brief sketch of the past century's progress in pure science.

the science of life and living things. Today these in turn have fathered a long list of descendants.

In all of them are those strains of character and physique which mark the family and give it unique power. Their stature comes from the insatiable curiosity and the habit of painstaking observation that marked the ancient astronomers and alchemists. Their shrewdness, foresight and wisdom are due to the discipline of logic, the careful methodical use of reason, which came into the family with Kepler and Newton. Their strength lies in their passion for measurement and the use of mathematics. Given these traits they needed only a firm grasp on the sleeve of nature to win her, in time, altogether. It is the mark of this century that they forsook the distant stars and began at the bottom, with the earth and rocks. Matter as such was the nearest and greatest mystery and needed to be solved before life and the universe, man and God could be approached intelligently.

No understanding of matter was possible until there was a definite answer to the question as to its ultimate structure. Is it continuous or discrete? John Dalton had proposed in 1808 that beyond a certain limit materials cannot be further subdivided and that the ultimate constituents of all materials are atoms, tiny individual particles which

are all alike for any one material. He had represented chemical reactions as being combinations of these atoms, or recombinations of them into new groupings. This was in accord with the behavior of gases as revealed by Boyle and Gay-Lussac. But no clear picture was possible until a further idea was introduced in 1855 by the Italian, Cannizarro, based on the hypothesis of Avogadro. He opened the way to better understanding by drawing a clear distinction between molecules and atoms. The smallest possible particle of any ordinary material, i.e., of any chemical compound, is the molecule. This is indivisible by any means except chemical, which is to say that when it is divided further it loses its chemical identity and a new material, or materials, is produced. A molecule is composed of atoms. The atom, on the other hand, is chemically ultimate and, until very recent years and under very exceptional treatment, could not be further divided. By distinguishing between molecules of compounds and atoms of elements Cannizarro made it possible to write chemical formulae which represented accurately not only the composition of molecules in terms of atoms, but also the composition of compounds in terms of elements. Thus it became possible to understand very fully the behavior of substances undergoing chemical reaction.

Within ten years atoms appeared real. The careful analyses of materials made by Berzelius, and new, more accurate ones by Stas, were now interpreted on the basis of the relative weights of individual atoms. By means of a table of atomic weights Mendeléef reduced the elements to an orderly system, predicted new ones which were promptly discovered; the resulting discoveries convinced all chemists that matter "acts as if" it were composed of atoms. The tremendous achievements in organic chemistry, with the building of hundreds of thousands of hitherto unknown compounds of carbon, became possible only on the basis of the atomic theory.

But atoms were not yet facts. Not until the twentieth century was that degree of truth attained. This grew out of the discovery of a class of elements whose atoms are unstable and give rise to rays of various sorts. Each atom of radium sooner or later explodes, sending off a succession of atoms of helium and becoming, in the end, an atom of lead. This natural conversion of one element into another, or into several others, revealed through the work of Becquerel, the Curies, Rutherford, and Soddy, changed the concept of the atom, proved that it is not ultimate, that it has an interior which is charged with enormous energy, and, incidentally, proved that the atom is

a fact, since the helium atoms ejected by the atomic explosion can in effect be seen and counted one by one.

Once the concept of atoms and molecules became definite and the composition of molecules was thoroughly understood, the bonding together of the atoms into molecules became the primary problem. For nearly the entire century the "valence" hypothesis proposed by Frankland served the purpose. It attributed to every atom a definite number of valence bonds, each of which was able to grasp a similar bond of another atom which it thus held in combination. The exact nature of these bonds could not be specified until the electronic structure of atoms became known some twenty years ago.

Nevertheless the theory of valence permitted the visualization of chemical structure and the writing of structural formulae which represented the frame-work by which atoms were combined. This device served to classify an enormous mass of knowledge and gave satisfactory reasons for the existence of many classes of compounds, such as the oxides, alcohols, and phenols. It revealed, furthermore, how and why certain combinations of atoms—such nuclei as benzene and ethyl—persisted through many chemical changes. Finally it gave an explanation of the course of reactions.

for it demonstrated that these various groups reacted, or did not react, according to their specific characteristics. It thus became possible to convert at will complicated compounds into a wide variety of modifications and ultimately led to the synthesis of extremely complex materials like the coal tar dyes. In recent years after a century of rearrangement of atomic valences, synthetic organic chemistry has achieved such triumphs as the synthesis of the hormones, epinephrin and thyroxin.

Meanwhile knowledge had been accumulating as to the conditions under which chemical reactions take place. Reactivity is affected not only by the affinities of the atoms concerned and the strength of specific valence bonds but by the conditions of contact and energy in which the molecules find themselves. Affinity and valence are covered by Mendeléef's periodic table but the energy relationships form a separate chapter of chemical history. It had been recognized long before that all reactions go more rapidly at higher temperatures and that a high temperature is essentially a condition of rich available energy. The necessity of providing energy for certain reactions was, however, not the whole story. Some reactions, such as combustion and explosion, give off large amounts of energy and yet do not

proceed until a certain minimum temperature is reached. The understanding of reactions therefore called for careful measurements of the energy relationships of the substances involved.

Another concept was, however, necessary for the understanding of reactions, namely, that of equilibrium. Guldberg and Waage, in the 1860's, first showed that reaction velocity also depends on the concentration of the reacting substances and of their products. Arrhenius in Sweden, and vant'Hoff in Holland, reduced this conception to mathematical form. Wilhelm Ostwald at Leipzig, and Walther Nernst in Berlin, built the great structure of thermodynamics on the basis of energy and equilibrium. Today thermodynamics together with electro-chemistry, i.e., the chemical effects of electrical energy; photochemistry, i.e., the relation of chemical energy and radiation; and the study of the conditions under which reactions take place in water solution, comprise the separate science of physical chemistry.

This in turn has found its justification during the twentieth century in its applications to industrial processes. It is the theoretical basis of all chemical engineering and its mastery is essential to the design and operation not only of chemical plants as such but of every factory that uses chemical processes,—which, be it noted, includes

the combustion of fuel under every steam boiler. The manufacture of rayon, for instance, requires all that chemistry has developed during the century in both the knowledge of molecular structure and the control of complicated and sensitive reactions by sound chemical engineering practice.

Meanwhile physicists had been studying energy as such. Heat was fairly well understood. Just at the close of the eighteenth century Count Rumford had shown that there is a direct relationship between the heat employed and the work obtained from it. But it was not until 1850 that the mechanical equivalent of heat was measured by Joule and utilized by Helmholtz to establish the principle of the conservation of energy. Energy became a reality when it was recognized as being just as indestructible as matter itself. It was Clausius who in 1857 established the kinetic theory of matter according to which Cannizarro's molecules are in constant motion, the motion itself being heat and their velocity being dependent on the temperature.

At the beginning of the century Faraday was investigating the relations between electricity and magnetism and the laws of the electric current on which all our modern uses of motors and dynamos are based. It was on November 24, 1831, that he demonstrated to the Royal Society that an

electric current can be produced in a coil of wire when a neighboring electric circuit is made or is broken. This has had vast consequences in engineering and the electrical industries, but, more important still, it led to the idea of electromagnetic waves in the mind of Clerk Maxwell thirty years later.

Light had been studied for centuries. During the 1820's it was accounted for as a wave motion in a hypothetical medium, the ether. The relationship between light and heat was established by Bunsen and Kirchoff in the 1860's. Thereupon Maxwell's theory of electro-magnetic waves combined all that was known of electricity and light and their conversion into heat. He proposed that these various forms of energy differ from each other only in the length of the ether wave. It is a human limitation that only a very narrow segment of the long range of wave-lengths is visible light.

As a direct outgrowth of this point of view Hertz discovered electrical waves belonging to the same family but measured in meters and kilometers instead of in millimeters. These were the waves employed by Marconi for the transmissions of signals by wireless.

Still deeper insight into the nature of electricity was, however, needed for the progress that has marked the twentieth century. This grew out of

the researches of Sir J. J. Thomson in England and the workers in radioactivity who have already been mentioned. It required also the work of Roentgen who discovered the X-rays and showed that they, too, belong to the family of electric waves, being distinguished from visible light chiefly by their extremely short wave-length. When all this knowledge was applied to the mysterious rays that are emitted by radium, during the first decade of the twentieth century, proof emerged that electricity itself is not a continuous fluid but is composed of minute particles. The first measurement of single electrons was made by Millikan at the University of Chicago in 1911. Thereafter the electric current became a simple concept: a stream of electrons pumped through a wire by a dynamo as water is pumped through a pipe. Their collisions with matter and with each other at various velocities give rise to the numerous types of electromagnetic waves.

This concept of the nature of electricity was of the utmost importance, for it permitted those more refined manipulations of electricity, such as the photoelectric cell, the X-ray tube and the hot-wire electric valve which is the heart of radio broadcasting and radio receiving. It did more than this, however; for the electron soon took its place as a constituent of every atom. Ruther-

ford, in explaining the phenomena of radioactivity, proposed the theory that all the mass of an atom is concentrated in an extremely dense nucleus at its center which is surrounded by electrons rotating in orbits. This theory was developed mathematically by Bohr, in Denmark, in such a way as to explain the behavior of atoms in relation to light and electricity; and chemically by Lewis and by Langmuir, in the United States, to explain the rôle of electrons in serving as the valence bonds that chemists had assumed for holding atoms together in molecules. The success of the electron theory and of this modern picture of the atom has revolutionized all of physical science. The atom is as real as ever, but instead of being a hard, indivisible particle, it is itself a minute solar system containing all its "matter" in a nucleus analogous to the sun, geometrically at least, and surrounded by from 1 to 92 electrons which perhaps move in orbits and which account for all the chemical and electrical properties of the atom. Both electrons and nucleus are relatively minute and, as in the case of the solar system, most of the atomic interior is empty space.

During the past five years attention has shifted to the nucleus itself. That too is not ultimate. It is a new world and one very difficult to conceive. It is composed of matter, and yet not of matter as

we know it, for—since it contains the entire mass of the atom in one-millionth of a billionth of the atomic volume—its density is a million billion times the density of "matter." Furthermore it is the seat of tremendous energy. When the radium nucleus explodes, helium nuclei are ejected at terrific velocities; other explosions send off electrons at nearly the velocity of light itself.

So at least these two particles are present in the nucleus. But other particles have been driven out by heavy atomic bombardment. They include protons (hydrogen nuclei positively charged), deutons (double hydrogen nuclei, positively charged), positrons (apparently electrons with positive charge), and finally neutrons, which seem to carry no electric charge. However, all these are but names today and giving them names does not mean that we know them. There may be yet others. How they get along together in the cramped confines of the nucleus and what reservoirs of energy they represent no one knows. The nucleus is a new universe and nearly every day there is good news and big news of a deeper penetration into this tiny speck which is the very heart of all matter. Today's progress is in these depths and its history cannot yet be written.

Finally, the century's greatest contribution, which became significant only in this last decade,

and which is likely to form the basis of progress during the century that lies ahead, is Einstein's study of time, space, and gravitation. It is an attempt to correlate electron and radiation phenomena on a minute, sub-atomic scale with the cosmic physics of the universe. It stands at present as a challenge to human thought.

So far we have considered only the physical sciences. Yet in the biological sciences the change of outlook in the course of the century was no less radical. There, too, a deeper understanding has led to a vast increase of power.

These sciences are more complex and they cannot give permanent answers until physics and chemistry, and especially biological chemistry, have furnished a much more solid foundation on which biology can be built. Yet the science of life is much more intimate to each one of us than the sciences of matter and of energy.

Man has had theories about life throughout his existence, long before natural science was born. Even the elementary progress that has been made has thus contradicted and upset many time-honored traditions. It has not been easy to substitute fact for legend. Hence the more striking are the consequences when it is accomplished.

Undoubtedly the greatest revolution in our outlook on life and the universe came with the

acceptance of Darwin's theory of evolution. This was published in 1859 and it required more than a full generation to be accepted by the world at large. But today evolution controls our destinies, and our understanding of that great principle of development is primarily responsible for the fact that these twentieth century days are unlike any that have gone before. The theory of evolution contributed more to the progress of mankind than many a new religion and it has awakened man to his possibilities more fully than any event in history, even more than did the Renaissance, that great awakening that brought light into the Dark Ages. Today the specific intervention of supernatural powers in human events is excluded from human thought just as the private governance of the sun and planets by the Greek and Roman gods died when the Christian era was born. Man looks to himself. He knows that he is the present climax of thousands of generations of evolution. He holds his destiny confidently in his own control. It is for this reason that he is so eager to understand the inner workings of nature, of his own body and especially of his mind. Here is the very well-spring of science and therefore of progress.

The study of evolution has indirectly led to consequences of the greatest importance. It has, for instance, led to a new understanding of geology

and to a correct history of those vast strata of rocks and soil whereon we live. It has therefore made possible the location of mineral deposits and multiplied the known natural resources of the earth. Furthermore, by controlled evolution based on the principles discovered by the Austrian priest, Gregor Mendel, man has learned to breed plants and animals of great economic value,—wheat that resists disease, cotton adaptable to specific climates, luscious fruits, cattle to furnish beef or dairy products.

But above all our century stands for progress in the medical sciences. Here we have the combination of all the sciences, expressed in human well-being. A record of medical progress during our century would almost be a history of medicine. A hundred years ago the idea had hardly been discredited that there are animal spirits residing in the organs of the body and in charge of their functions. The circulation of the blood was understood, as was also the function of oxygen in the blood. Beyond this little was known. The function of the nervous system was the first subject to be placed on a modern basis. There was tremendous progress between 1830 and 1870 in the understanding of digestion and nutrition, in the revelation that tiny cells are the actual basis of bodily structure and in the realization that dis-

ease is in nearly every case an affliction of these cells. In the years that followed, the various specific diseases were attacked on this basis.

Much fundamental work required the coöperation of chemists. The digestive system particularly is a chemical system and Liebig's study of foods and the differentiation of proteins, carbohydrates and fats was fundamental to an understanding of digestion and therefore of healthy living. The rôle of enzymes in digestion was of the utmost importance in nutritional diseases. Finally, in the twentieth century the discovery of vitamines opened a new chapter in food chemistry.

Even more far-reaching in its effects was Pasteur's study of the process of alcoholic fermentation. Known and used through the ages for the production of wine and beer, it had remained mysterious until Pasteur showed that the chemical conversion of sugars into alcohol was attributable to certain microörganisms. The logical extension of this work showed that similar organisms were involved in a long list of infectious diseases of animals and man, including tuberculosis, diphtheria, typhoid fever, meningitis, and many others. Lister's development of aseptic surgery with all its consequences for the race is only one result of Pasteur's work. Preventive medicine today leans heavily on inoculation by antitoxins, for defense

against diseases in which infection cannot be avoided. In this too it owes much to Pasteur.

There is a field in biological science which holds much promise for the future, namely, the chemical study of the ductless glands of the body which by obscure chemical catalysis seem to control the other functions of the body;—and not only such obvious functions as digestion, growth, and the maintenance of temperature, but those more mysterious functionings of the mind and the emotions which are summarized in the term "personality." This promises to lead into a real science of psychology so that the future is quite likely to reveal a greater rate of progress in the psychical sciences than in the physical.

This deeper knowledge we have acquired has all had to do with matter and energy—with what things are made of and what makes things function. Deeper knowledge concerning energy is a powerful tool in building a better physical structure of civilization and causing it to function more efficiently. But the structure itself calls for materials, that is, for various forms of matter, and the choice of material has much to do with the way things function.

CHAPTER VIII

THE RÔLE OF MATERIALS

ENERGY, in performing the work of the world, operates through materials and mechanisms. The efficiency of a mechanism depends on design and material. Different materials as well as different designs vary greatly in their suitability for employment in a given mechanism. Initially, design provides the important advance; eventually, in any given type of mechanism, material becomes the determining factor.

Thus, in mechanical invention use is made of the most suitable of available materials, after which effort to improve design is likely to be continued to the point of diminishing returns. At this point advance tends to wait until improvement in the materials of construction or of energy supply shall have provided new degrees of freedom in mechanical invention looking to better energy conversion, that is, increased efficiency.

The development of new and better materials has increasingly characterized the past quarter century. This has made possible increasingly rapid advance in the mechanical and other arts.

Evidently Ralph Waldo Emerson was thinking in terms of mechanical invention only when, in the eighteen fifties, he wrote:

"'Tis a curious chapter in modern history, the growth of the machine shop. Six hundred years ago Roger Bacon explained the precession of the equinoxes, the consequent necessity of the reform of the calendar; measured the length of the year, invented gunpowder; and announced (as if looking from his lofty cell over five centuries, into ours), 'that machines can be constructed to drive ships more rapidly than a whole galley of rowers could do; nor would they need anything but a pilot to steer them. Carriages also might be constructed to move with an incredible speed, without the aid of any animal. Finally, it would not be impossible to make machines which, by means of a suit of wings, should fly in the air in the manner of birds'." "But," said Emerson, "the secret slept with Bacon. The six hundred years have not yet fulfilled his words."

Of course, Bacon never really had the secret. What he had was an imagination and faith in the possibilities of the experimental method, which, as we have seen, he himself was the first to emphasize. But even when Emerson wrote there had been no mean degree of fulfillment of Bacon's prophecy. Ships were being propelled "more

rapidly than a whole galley of rowers could do;" rail-borne carriages had been constructed "to move with an incredible speed without the aid of any animal;" both, thanks to mechanical ingenuity in the use of materials which nature had provided or which, for the most part, had been slowly developed through the experience of the ages. But carriages that would run with equal rapidity on the highways, and machines that would "fly in the air in the manner of birds" waited on further invention, invention of new materials as well as of new mechanisms.

To illustrate. When those of us near the half century mark were boys our idea of a road-going automotive vehicle was the steam tractor that towed the threshing machine from farm to farm and provided the power for threshing. No one can say it did not serve the purpose for which it was primarily designed, which was that of a stationary engine. When it traveled it was not far, and it had a heavy load to pull. We felt that it had to be heavy because it had to be strong, from its boiler, which must withstand the steam pressure, to its every other part, for the heavy boiler had to be supported and the heavy thresher had to be pulled along the rough and rutty road. Its tires of steel were broad and its speed was slow. We reasoned it could not be much different.

Then came the gasoline engine, with its heavy fly wheel that kept things going when the engine missed fire; and this it seemed to have been constructed to do. But it pumped water with greater dependability than the windmill. As a stationary power machine it was a success. Mounted on wheels, it would have provided more power per unit weight than the steam engine. If applied to a road vehicle it would have represented a step ahead. A new mechanism, the internal combustion engine, employing as the source of power a new material, gasoline, made possible higher efficiency.

About the beginning of our present century attention was turned toward perfecting an automotive vehicle intended to go places on the highway, not to furnish power, except as a good Samaritan in emergencies, which in the early days were less rare than now. This was a very different problem. What was now called for was a maximum of power and a minimum of weight consistent with adequate strength and endurance. Cast iron and mild steel answered very well for the old steam tractor and the stationary gasoline engine. But now the strongest of steels was called into use, as the public, or that part of it able and willing to support the new industry, clamored for more speed, more comfort, more style. Soon the possi-

bilities of the best of the time-honored materials of construction were taxed to the limit. It was no longer purely a mechanical problem, it was becoming a chemical problem. It became more than ever a chemical problem when the idea of mass production took form as a means of providing a car for every family at a price it could afford to pay. In either case it was special steels, and special abrasives, that came to the rescue. Alloy steels employed in the car's mechanism gave much greater strength per unit weight. Alloy steels employed in machine tools were able to cut at a faster rate than the best high-carbon steel. Synthetic abrasives approaching the diamond in hardness, bonded into grinding wheels by means of a synthetic resin that was strong and unsoftened by frictional heat, made possible higher speeds and higher cutting rates.

But the car had also to be made comfortable and able to withstand road shocks. Research had already provided vulcanized rubber, but not rubber such as has since been developed. The difference between a tire mileage of five thousand and twenty-five thousand and a like ratio in years of resilient life has been contributed in large part by chemical research, which has provided means for accelerating vulcanization and adding to the strength and life of the rubber.

When the early automobilist was pulled up alongside the road for repairs, more often than not it was due to ignition trouble, and this, in turn, to the fact that the electric insulation softened and got out of shape from the heat of the engine. A synthetic resin came to the rescue by providing insulation that could be depended on to remain rigid under heat and be unaffected by oil, gasoline, or water. What was no less important, its products lent themselves readily by hot-molding to the rapid production of accurately dimensioned, replaceable parts. For good measure, it also provided a timing gear, which, meshed with steel gears, ran noiselessly and lasted the life of the car.

When increased safety from splintering glass of windshield and side windows was the demand, another plastic, product of chemical research, clear and white, was quite literally pressed into service as the middle layer between two sheets of plate glass; and now the chemist has invented another plastic for this same use, one that better withstands sunlight.

When the old-time natural gum varnishes and enamels were retarding production and adding to the cost of finishing by requiring many coats and two or three weeks to complete the job, chemical research provided a superior coating material

that gave a complete and better job in less than a day, with only a few coats, and made it possible to provide tints as light and colorful as could be desired by the most dashing of prospective owners; and all at a lower cost.

When a scarcity of light petroleum distillate was threatened, research provided ways and means of producing a better and equally light motor fuel from heavy oil, of which there was an abundance.

When greater motor efficiency and smoother operation became the demand, an engineer, turned chemist, invented non-detonating gasoline, the "ethyl" gasoline offered on every hand to-day.

When—but the point is no doubt clear: The automobile is a wonderful achievement, thanks to superb engineering, mechanical, electrical and chemical. Its further development is likely to be dependent on new or improved materials as much as, or more than, on new or improved mechanical design.

Pretty much the same is true of the development of the airplane, and the dirigible balloon, both of which inherited much from the automobile; but they had their special needs. Their need for extreme lightness with great strength was met by new, light metal alloys whose main constituents, aluminum and magnesium, form such a large part of our earth's crust that they may be

depended on to keep us in the air and serve us on terra firma long after our visible supply of iron has been exhausted.

A similar story may be told concerning present or possible future developments in not only machines and fuels, but in every other physical thing that man requires, whether roads, buildings, electronic devices, textiles, foods, or medicines. Is it roads that are wanted? The modern highways that are being extended into every part of the country are of reinforced concrete, an important mechanical invention employing materials, Portland cement and steel, developed through chemical research. Is it buildings? Modern structures employ these same materials, alone or in conjunction; also many others that are chemical achievements not products of nature—brick, tile, plaster, paper, coatings, plastics, noncorroding metals and alloys. Electronic devices? Filaments and their special treatments are basically chemical problems and products. Textiles? Rayon threatens the silk worm with extinction. Foods? They will no doubt long be mainly the products of plant and animal life, yet agriculture's immediate problem is over-production, due in large measure to increased soil fertility, a product of chemical insight concerning the materials of plant and animal sustenance; also, synthetic vitamines represent a

reasonable future expectation. Medicines? The greatest future advance in the art of healing is likely to be along chemical lines—chemical specifics, such as arsphenamine ("606"); synthesized hormones, such as thyroxin, which so profoundly influence us, physically, emotionally, mentally.

In them all, materials hold the key to future progress, because the architect, the engineer, the manufacturer, the agriculturalist, the physician, is limited in his accomplishment by the character of his available materials, whether structural, energy-producing, nutritive, or curative.

Nearing the end of engineering advance, the end of material progress? Yes, and the end of our power-maintained civilization if there is to be an end of new and better materials for structure and energy supply. We have developed our major progress to date on iron, coal and petroleum, all of which are far from inexhaustible. Without progress in materials, physical bankruptcy lies ahead.

But considering that our practically inexhaustible supply of the light metals is available, through research, for improved utilization, and considering that we are only on the threshold of knowledge concerning other possible energy sources, we shall confidently look forward to a new era of engineering, a new and greater civilization.

We have had a glimpse of our century's advance in new knowledge concerning matter and energy. We have come to recognize that "material" progress is eventually limited by progress in materials. In nothing is research more justified by its works than in the creating of new materials for new and better utilization.

CHAPTER IX

NEW REQUIREMENTS, NEW MATERIALS

MAN has always needed food, and has needed or desired clothing, shelter, and some form of recreation. A sustaining measure of these Nature has provided, or we should not be here. But human desire has grown with knowledge, and, although, in the matter of food, man remains fairly close to Nature, or is daily admonished to do so, still in the matter of shelter his tastes and achievements have run all the way from the cave to the castle; of clothing, from animal skins to "artificial silk;" of recreation, from racing to radio.

All this time man has been specifying, less or more, his requirements in terms of form, performance, and material. As he became more exacting in the matter of form or of performance, he often found his desires thwarted by the inadequacy of the materials available. So it has come about in the course of a very long time that those who were more interested in things than in materials began to get help from those who were

more interested in materials than in things. The latter class, the chemical scientists, made new combinations of materials; they wrested metals from their ores, metals which had never before been seen; they combined these with other metals to produce alloys of new and superior properties; they modified natural materials until one would not recognize them; and they built up, they created, from simpler substances, or from the elements themselves, materials that had never before existed. The scientists found this all so interesting that they did not wait to learn whether or not a new material was needed for some practical use; in fact they did not care, but kept right on making new materials by the hundreds and thousands, so that new materials began to look for suitable uses while new uses were looking for suitable new materials. In this business of making things artificially some workers became so skilled, and so impressed by the possibilities of their creative ability that they began to think in terms of making materials of much more than ordinary value to humanity, even of making in the laboratory certain all-important materials that Nature may have failed to make in sufficient quantities in the living body to insure continued life and health.

This is all very general, of course. Let us consider a few specific cases.

At present our most widely employed and versatile metal is iron. As smelted from its ores it contains, among other impurities, two and a half to five per cent of loosely held carbon which makes it brittle, but also makes it fluid when heated to white heat, so that it can be poured into molds and thus be made to take any desired shape when cool. We call it cast iron. It is cheap and useful. When a tough iron was wanted we burned out most of the carbon in a "puddling" furnace. This made the iron pasty when hot and malleable when cold. When we wanted it hard, strong and elastic we found that one per cent, more or less, of carbon was about right; also that we could make it very much harder if we heated it to a dull red and then cooled it suddenly. This product has proved very useful. We call it steel. First we made steel by packing wrought iron in charcoal and keeping it hot for weeks. To make steel quickly air was blown through molten cast iron thus burning out all the carbon. The small amount of carbon wanted in the steel was then added. This made steel much cheaper, and therefore, available for many additional uses.

But we have only begun with steel. Experiment later showed that certain other "impurities" besides those "natural" to iron make a tremendous difference. Silicon to the extent of 15 per cent

makes it rust-proof and acid-resistant. Tungsten and manganese or chromium give a steel that is hard without tempering and that remains hard at a bright red heat. Used in machine tools, the work can be pushed several times faster than when the best carbon steel is used. Manganese alone, 11 to 14 per cent, gives a steel too hard to cut; it has to be ground. Chromium, 12 to 14 per cent, gives a "stainless steel." Addition of nickel makes it more easily worked. Nickel, alone up to 15 per cent, makes steel stronger; 25 per cent gives a non-magnetic alloy. A steel containing 36 per cent of nickel, and 5 per cent of manganese ("Invar") has a very low heat-expansion; it finds use in instruments of precision. One containing 46 per cent of nickel ("Platinite") has, like platinum, the same heat-expansion as glass and may be used in place of platinum for the lead-in wires of electric lamps. "Permalloy," 80 per cent nickel and 20 per cent iron, may be very rapidly magnetized and demagnetized. It is used in telephone and marine cable lines to speed up the rate at which signals may be sent.

"High-speed" alloys for tools may be made with no iron at all. "Stellite" is composed of chromium, cobalt, and tungsten. "Carboloy," composed of crystals of tungsten carbide cemented together with cobalt, is harder than corundum and

yet tough enough to be used as the point or edge of a cutting tool. Tungsten metal itself is very hard and ordinarily not ductile, yet Coolidge and his associates worked out a process by which it is drawn into the fine electric lamp filaments that have removed millions annually from the country's lighting bill.

These metal alloys are prepared in the heat of the electric arc. With the aid of such an "electric furnace" Moissan, in France, in 1894, made tiny diamonds out of charred sugar. Some of the electric furnaces employed in metallurgical operations to-day are very large. They provide high temperatures; also freedom from impurities such as are introduced when fuels are employed.

Fashioning these hard alloys economically called for a very hard abrasive. Acheson made one in the electric furnace out of clay and charcoal. Chemists call it silicon carbide. He called it "Carborundum."

But electricity has found use in metallurgy in a different way. Mention has been made of Hall's electrolytic process for aluminum. Hall, twenty-two, just out of Oberlin College, working at home with very simple equipment, discovered that the mineral, cryolite, when fused would dissolve bauxite (aluminum ore), and that an electric current passed through the fused mass would deposit alu-

minum at one of the poles. Before Hall aluminum was merely a laboratory curiosity, although there is more aluminum in the earth's crust than iron, and 4000 times as much as copper. In 1929, three hundred thousand tons of it were produced, and seven billion kilowatt hours of electric energy were consumed in doing it.

Magnesium, also deposited from a fused electrolyte, is somewhat lighter than aluminum. Alloys of aluminum and magnesium, because of their lightness and strength, are finding use in the construction of airplanes and dirigibles. Aluminum with five to ten per cent of magnesium gives an alloy known as "Magnalium" which has been described as "almost as light as aluminum and almost as strong as steel." A few tenths of a per cent of lithium, lightest of metals, added to aluminum are said to provide properties somewhat similar to those of steel.

It is being freely predicted that another decade will witness a marked lightening in transportation equipment and marked increase in speeds; also similar lightening of architectural structures.

In new metal alloys the engineer is being given new degrees of freedom, namely, lightness with strength, special magnetic properties, and high resistance to corrosion.

But we are not through with the electric furnace. At certain temperatures coal and limestone combine to form calcium carbide. Calcium carbide and water give acetylene gas; and this introduces us to almost limitless opportunities in organic synthesis, that is, in the artificial production of organic compounds.

Employing acetylene as a basic material it would be possible, though not necessarily profitable, to build practically any organic compound. Acetylene bubbles through water without combining with it, but if a mercury salt and a little acid are present the acetylene combines with the water to form acetaldehyde, a liquid having a pungent, ethereal, suffocating odor. If the vapors of acetaldehyde and hydrogen are passed over finely divided nickel, ethyl or "grain" alcohol is formed. This alcohol, without benefit of malted grain or molasses, is identical, of course, with that obtained by yeast fermentation, and entirely different from "wood alcohol," or methanol, which used to be made entirely by the destructive distillation of hard wood, but is now made mostly from coal and water, or, more specifically, from carbon monoxide and hydrogen which are formed when steam is passed over red-hot coal.

The mercury salt and acid and the nickel mentioned above are called "catalysts." They

are necessary, though nobody knows just why. The right one is obtained by trying one substance after another until the best one is found. Employing a suitable catalyst we may oxidize acetaldehyde to acetic acid, the acid of vinegar. From acetic acid may be prepared acetone, a very useful solvent. Acetone and acetylene may be made to combine forming isoprene which under proper conditions turns into an artificial rubber, but not as cheap a product nor, so far, as good as that obtained from the rubber tree. Oenslager and others connected with the research organizations of large rubber manufacturers have been able by the use of organic "accelerators," "antioxidants" and suitable compounding materials to speed up the vulcanization of rubber, increase its strength and resistance to wear, and retard its oxidation, or aging. The improved character of automobile tires to-day is partly due to mechanical construction but much more to chemical "construction." The latest synthetic rubber-like substance is polymerized chloroprene, trade-marked "DuPrene." It is a derivative of acetylene, as are also a synthetic drying oil known as S. D. O. and certain recently developed synthetic resins, known as "Vinylite."

If we had to do so we could make our coal-tar dyes and medicinals from acetylene as a basic

material, since acetylene may be made to combine with itself (polymerize) to form benzene, naphthalene, and allied products, which are the bases of these dyes and other "aromatic" compounds. Just now, however, it is cheaper to get our benzene and the like from coal tar.

Also from coal tar we can separate a little phenol, or carbolic acid, but there is not enough so it is made also synthetically, from benzene. At one time phenol was chiefly used as a disinfectant, but for a number of years it has been employed in large quantities together with that other well-known disinfectant formaldehyde, in the production of synthetic resins of the Bakelite type, invented by L. H. Baekeland after exhaustive research. In their finished, hardened state these "phenolic" resins are strong, infusible and insoluble. As molded and other forms they are employed in electrical insulating devices, silent gears, table tops, as the bonding agent in grinding wheels, in the preparation of protective coatings, and in many other uses. Baekeland's work stimulated similar research everywhere. Out of it have come other synthetic resins of importance; among them are the urea-formaldehyde resins whose outstanding characteristic is the permanence of their natural light color. They are best known under the trade-name, "Beetle." Also

there are the "Glyptal" type resins, whose chief use is in protective coatings. Synthetic resin paints, varnishes, and enamels have quicker drying, and better wearing and weathering properties than those prepared from the time-honored natural gums and resins.

In the synthetic coatings field, the cellulose lacquers at present enjoy a large use. It is with them that automobiles are finished in less than a day instead of two or three weeks as formerly. The base of cellulose lacquers is a "nitrated" cellulose, a sort of mild gun cotton, known as pyroxylin. It was pyroxylin that Hyatt, by addition of camphor and a little solvent, made into a tough, flexible, transparent material, called "Celluloid," which has found its way into many uses—camera film, the middle layer of shatter-proof glass, and numberless molded articles, such as combs, brush handles, and the like.

But pyroxylin is inflammable. For moving picture film this is a decided objection. To overcome this objection cellulose acetate which is non-inflammable has been developed. Also cellulose acetate is less readily discolored in sunlight than pyroxylin, so it also is being used in shatter-proof glass. It was cellulose acetate solution, known as "dope," that was used during the war to coat airplane wings.

Cellulose is the structural material for all plants. Cotton fiber is almost pure cellulose, which suggests another use of cellulose products, namely, textiles. Cellulose acetate is much employed in making artificial textiles known in the trade as "Celanese." Another cellulose product, viscose, finds extensive use as a textile fiber under the name, Rayon. Artificial fibers are spun much as the silk worm spins silk. In the case of Rayon, for instance, a thick solution of cellulose xanthate prepared by treating cellulose with caustic soda and carbon bisulphide, is forced through very fine holes into an acid solution which changes the cellulose xanthate back into cellulose, which, in turn, is insoluble and therefore remains in the form of fibers. Cellophane is the same material made in sheet form.

But, while the inflammability of cellulose nitrate is objectionable in a plastic, in another class of cellulose products, the explosives, it is desirable to introduce even greater instability. In gun cotton, the process of "nitrating," or treating with nitric and sulphuric acids, is carried still further. After nitrating, the cotton is still fibrous. To keep it from burning too fast it may be dissolved in ether and alcohol to a plastic mass, squirted into rods and cut into grains of a size that will burn at a proper rate. This is a "smokeless powder."

In these explosives, it is the nitrogen that is loosely held in the compound and that "lets go" with violence. Nitrogen combines with other substances, also, to form explosives. One of these is glycerine. The nitrated product is called nitroglycerine. It must be handled with extreme care as it may explode from a slight jar. Alfred Nobel, a Swedish chemist, manufactured nitroglycerine. One day the container in which he had packed some of it sprang a leak and the nitroglycerine was soaked up by the packing material, "kieselguhr." That is how dynamite was discovered. It was noticed that the nitroglycerine-kieselguhr mixture could be handled safely without special care yet was powerful enough when deliberately set off. Later Nobel used gun cotton to soak up nitroglycerine. The product, a very powerful explosive, is called blasting gelatine.

Picric acid, a nitrated phenol, is a disinfectant, but also a powerful explosive. Another and more important explosive is made by nitrating toluene. Tri-nitro-toluene, known for short as T.N.T. was much used during the World War, as it is both safe and violent. It may be handled roughly and even set on fire without danger, yet a percussion cap of just the right sort causes it to explode with great violence, producing a smoke that is black,

which aids in locating the "strikes" of shells loaded with it.

It is evident from the foregoing that nitric acid is of considerable use in both peace and war. It will be evident from what follows that it is much more necessary in peace than in war. Wars up to recent years have been fought without it, but plants cannot live without it or its equivalent in the soil, and we cannot live without plants. In wild nature one generation of plants gets it from the remains of the last, and every time there is a thunder shower a little is formed in the air by the lightning, and is washed into the soil. Still when the lands are cropped the soil soon becomes depleted and a fresh supply must be added. Certain types of plants, known as the legumes, the pod-forming plants, including peas, beans, clover, alfalfa, are able to get it from the air, which is four-fifths nitrogen, by the aid of bacteria in nodules on the roots; but most plants are not thus favored.

While we have to exercise care to prevent the oxygen of the air from combining with the wood of our houses or the steel of our bridges, the nitrogen had us worried for a time lest we should be unable to learn how to get it to form compounds in sufficient quantities to keep us eventually from starving. In 1898, Crookes, of Eng-

land, uttered a solemn warning that mankind was faced with starvation relatively soon, unless something was done about it. The only large natural supply of "fixed" nitrogen we have any knowledge of is in Chili. It would not last indefinitely and we had no way of replenishing it. In our first attempts to get it from the air, we employed artificial lightning, electric sparks. But this took a great deal of power, and was not feasible unless we had a very cheap source of power. Niagara, and water power sites in Norway looked promising and were utilized for this purpose, but then it was discovered that nitrogen could be fixed more cheaply by passing it over hot calcium carbide, which combines with it forming calcium cyanamide. This was the approved method with us during the war, though it has since then become obsolete, and the government put millions into a cyanamide plant at Muscle Shoals, Alabama, and millions additional into an experimental plant at the same place to try our hand at the direct synthesis of ammonia from nitrogen and hydrogen by the Haber method, already referred to as the method that served Germany so well during the war. Fixing nitrogen as ammonia by the Haber process requires relatively little power and is cheaper than by the cyanamide method. The Haber

process depends for its success on a specially prepared iron catalyst, and on moderate heat and high pressures. By the aid of platinum as a catalyst the ammonia may be oxidized direct to nitric acid. It is reassuring to know that to-day there are two American companies employing the Haber process, either of which would be able to meet our whole "fixed" nitrogen requirements in case of war, and not have to rob agriculture to do it.

But agriculture needs more than fixed nitrogen to maintain soil fertility. It needs, principally, phosphates and potassium salts. The phosphates we have in abundance; more than the rest of the world. Up to the time of the war, Germany had a practical monopoly of the potassium salts, but prices went high and made the working of lean deposits profitable. After the war only one of the new "potash" industries over here could be continued with profit. That one had been put on a strictly scientific basis by a one-time professor of chemistry, John Teeple, who worked out the complicated details of separating the potassium salts from the other salts of the brine of Searles Lake in California.

As already suggested, feeding plants is the first step in feeding animals. With the aid of sunlight, plants build the proteins, starches, sugars, and fats needed by animals for growth and mainte-

nance of their bodies and for heat and muscular energy. Plants build these complex food materials from the carbon dioxide of the air (of which there are only about four parts in ten thousand) and the water, nitrogen compounds, and a few minerals that are in the soil. Animals get their energy by oxidizing and breaking down these complex food materials into carbon dioxide, water, and simple nitrogen compounds, which thus again become available as plant food. This cycle is as old as life. Chemical effort has been directed along lines of better plant and animal feeding. When, some day, we learn the secret of chlorophyl, the green pigment of all leaves, and how by utilizing the energy of sunlights it builds proteins, starches, sugars, and fats we may be able to make food out of the elements, nitrogen, oxygen, hydrogen, and carbon, but this is not saying that it would be profitable. The chances are we shall long remain content to let the plants do their quiet, efficient work for us.

There is a class of foods, however, which we could make with great profit. This is the vitamines; so necessary although needed in such small quantities. It is confidently predicted that eventually we shall be synthesizing these indispensable "protective" foods.

A field in which Nature has not done much for us

and synthesis has done a great deal is that of dyes and organic medicinals. The first "coal tar" dye was made by William Perkin, in England in 1856. Perkin, as a boy of eighteen, was trying to synthesize quinine when he accidentally discovered mauve; such are the accidents of science! But it was in Germany that the fifteen hundred, more or less, synthetic dyes were first developed. Now they are made of at least equal quality in the United States and are sold cheaper than the foreign dyes were sold before the war. The story has often been told of how the growing of indigo plants and madder was rendered unprofitable by the synthesis of their respective coloring matters, indigo and alizarin. The important thing is that synthetic dyes are cheaper and better than natural dyes. To-day we should miss their brilliance if we had to depend on what Nature is able to provide, unaided.

There is practically no limit to the possibilities of organic synthesis. Slosson, in his *Creative Chemistry*, says: "The building up of the synthetic kingdom starts with the simple atom of carbon, which is by itself the most precious of substances, as the diamond, and the most valuable of substances, as coal. The simplest compound of carbon with oxygen is carbon monoxide; the simplest compound of carbon with hydrogen is

methane; the simplest compound of carbon with nitrogen is cyanogen; the simplest compound of carbon with nitrogen and hydrogen is hydrocyanic acid; the simplest compound of the four elements is urea. All these are important commodities and from these may be made all the innumerable compounds of animal and vegetable life and of the annex to Nature, Beilstein's dictionary."

Whether it will pay to try to make some specific compound depends on how great the need for it is. Ehrlich, in Germany, saw the great need for something that would kill the disease germ of syphilis without injuring the patient. The six hundred and sixth compound he made and tried out worked; and so we know it by the number "606"; its official name is arsphenamine. The next drug of value in Ehrlich's series was neoarsphenamine, No. 914. When Ehrlich died he had made and tried out about twelve hundred different compounds, but found nothing else of great value. Rockefeller Institute made and studied tryparsamide, and showed its value in African sleeping sickness; Loevenhart and Lorenz, at the University of Wisconsin, discovered it had great value in paresis.

Also worthy of special mention in this general field of "chemotherapy" is the work of Roger Adams at the University of Illinois on the syn-

thesis of chaulmoogra acids, which are even better than chaulmoogra oil in the treatment of leprosy.

Not content with destroying disease germs as a means to health, organic synthesis has assumed the task already referred to, of helping Nature in her own laboratory. Ductless gland secretions are such determining factors in the normal functioning of the body that the isolation of the active principle of each, followed by analysis and final synthesis, represents a rare opportunity for chemistry in its service to mankind. Two of these active principles, epinephrin and thyroxin, have already been synthesized and are available to the medical profession. These are very potent substances. Epinephrin, which exerts a profound influence over blood pressure, may be detected biologically in a dilution of one part in three million; while the whole amount of thyroxin needed to make the difference between idiocy and normal mental health for the period of a year is said to be only 3.5 grains. Another of great importance is insulin, a deficiency of which produces diabetes. At last accounts its synthesis had not yet been effected, but this and other hormones are at present the subjects of active investigation.

As is evident from the foregoing, the "science of the transformation of matter" touches life in all

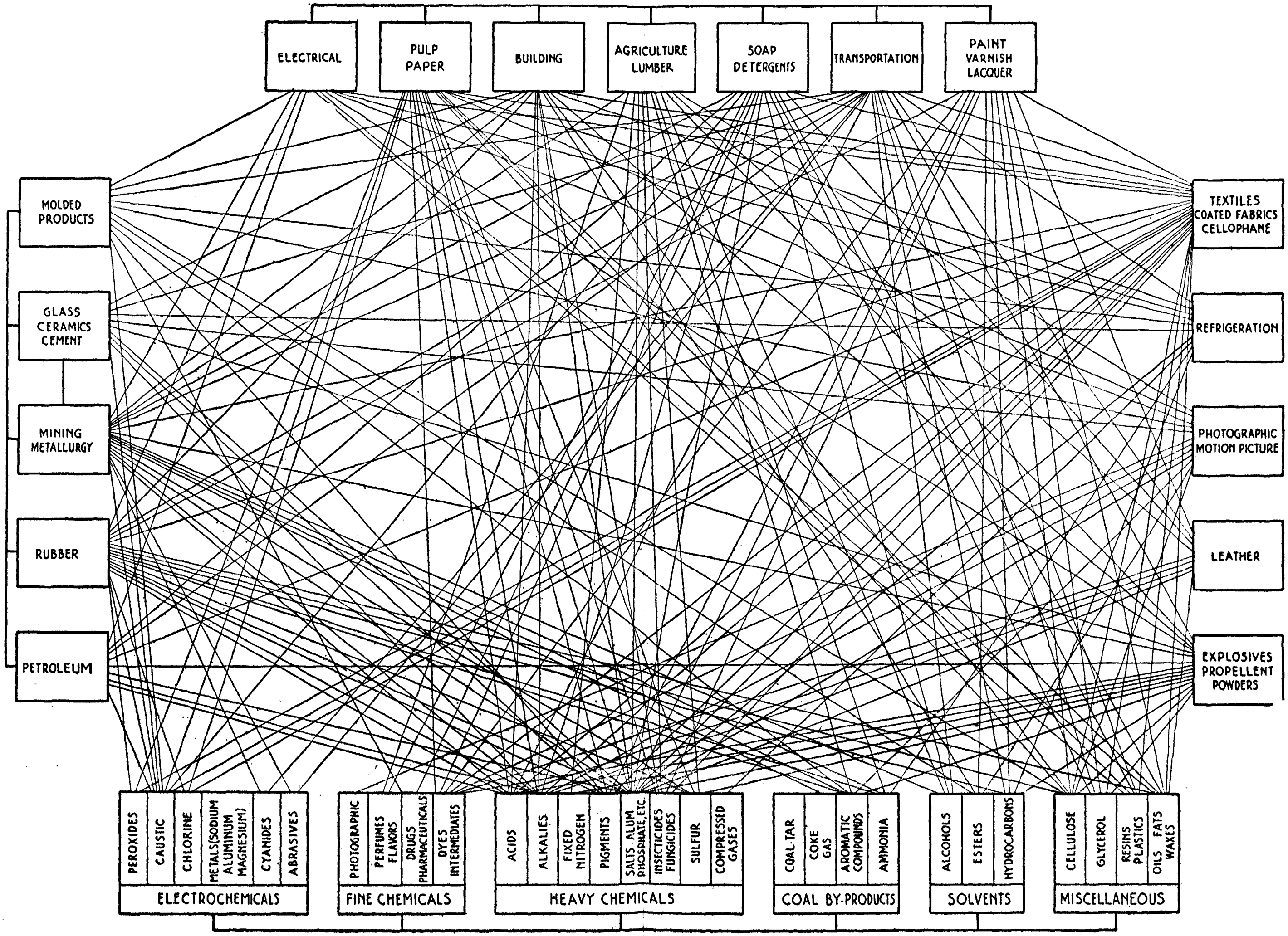

ELECTRICAL
PULP PAPER
BUILDING
AGRICULTURE LUMBER
SOAP DETERGENTS
TRANSPORTATION
PAINT VARNISH LACQUER
MOLDED PRODUCTS
GLASS CERAMICS CEMENT
MINING METALLURGY
RUBBER
PETROLEUM
TEXTILES COATED FABRICS CELLOPHANE
REFRIGERATION
PHOTOGRAPHIC MOTION PICTURE
LEATHER
EXPLOSIVES PROPELLENT POWDERS
PEROXIDES
CAUSTIC
CHLORINE
METALS (SODIUM ALUMINUM MAGNESIUM)
CYANIDES
ABRASIVES
ELECTROCHEMICALS
PHOTOGRAPHIC
PERFUMES FLAVORS
DRUGS PHARMACEUTICALS
DYES INTERMEDIATES
FINE CHEMICALS
ACIDS
ALKALIES
FIXED NITROGEN
PIGMENTS
SALTS, ALUM PHOSPHATE, ETC.
INSECTICIDES FUNGICIDES
SULFUR
COMPRESSED GASES
HEAVY CHEMICALS
COAL-TAR
COKE GAS
AROMATIC COMPOUNDS
AMMONIA
COAL BY-PRODUCTS
ALCOHOLS
ESTERS
HYDROCARBONS
SOLVENTS
CELLULOSE
GLYCEROL
RESINS PLASTICS
OILS FATS WAXES
MISCELLANEOUS

Figure 1

its phases. Thus chemical industry is related to all other industry. But the term, chemical industry, is usually restricted in its application to those industries engaged in the production of materials that we call "chemicals." They are of service principally in preparing materials used in every-day life. Thus chemical industry, employing sulphur as a raw material, prepares sulphuric acid which finds use in many ways: from the making of fertilizers to that of dyes; from the refining of petroleum to the plating of metals. From common salt and water, chemical industry prepares caustic soda, soda ash, sodium bicarbonate, variously needed in the production of soap, glass, paper, foods, drugs, and many other materials we all know and use. As by-products, when caustic soda is made electrolytically from common salt, we get chlorine, much used in bleaching and water purification; also hydrogen now employed on a large scale in the so-called hydrogenation of vegetable oils to produce lard-like fats, and in the hydrogenation of very heavy mineral oils and even coal to produce motor fuels and lubricants.

Figure 1 is designed to impress if not to inform the reader concerning the intimate *Relation of Chemical to Other Industry.* It was employed to illustrate a recent address under the above title by C. M. A. Stine, director of the research

of a chemical manufacturing company founded in 1802 by Eleuthère Irénée duPont de Nemours, who had done service under Lavoisier in the French government's powder works. It was made available through the courtesy of Dr. Stine and *Industrial and Engineering Chemistry*.

In all industry to-day research is being emphasized and being organized. Following the World War we began to see as never before that future success lies in organized research, scientific and applied.

Our years of free-lancing in discovery and invention had brought big returns, but at needless expense in time, money, and personal sacrifice. Besides, the problems were becoming more complicated, and it became apparent that if such work in unexplored fields is to be conducted on a relatively small scale, as by an individual company instead of by the whole nation, it must, like any other enterprise that is operated for profit, be run on a business basis. While the nation has an obligation to future generations as well as to the present, and while private endowment may waive tangible returns of any sort, invested capital properly demands a reasonable assurance of profit and that in its own day and generation.

So let us now consider somewhat in detail the business of inventing new materials.

CHAPTER X

THE BUSINESS OF INVENTING NEW MATERIALS

"You will know him when you see him; he has on an India-rubber cap, stock, coat, vest, and shoes, and an India-rubber purse without a cent in it." In this fashion, tradition says, a neighbor described Charles Goodyear who invented the process by which caoutchouc was made useful. And how useful!

A toast and a tear for the lone inventor! Well has he served mankind. We mocked until he finally achieved, and later gave him grudging pittance. But what of him who tried and failed? We know him not, yet his name is legion. His personal sacrifice was part of the price paid for progress. The price was great yet the returns were greater.

Thus was research early justified, but the unnecessary personal hardship, never. It was not good business, but we did not see it; not until the war awakened us. Then we took a leaf from the book of practical experience and organized the business of inventing to speed it up and improve its chance of success.

As work in a given field proceeds, it tends to become of a character that can be handled by trained researchers only. Compare, for instance, Goodyear's discovery of the rôle of sulphur in vulcanization, after ten years of experimenting, by accidentally dropping on a hot stove a caoutchouc-sulphur mixture that he had cured in the sun, and had no thought of heating further—compare this with the recent production of a synthetic rubber starting with acetylene, a gas, which in turn goes back to coal and lime as starting materials. Someone trained in organic chemistry was needed here; and special training is needed everywhere in the research of to-day. Organized research has not been slow to recognize this fact. Then, too, it is a matter of experience that two or more researchers working to one common purpose will accomplish much more by coöperating. A fact of little or no value to the work of the individual making its discovery may often prove of great value to work being conducted by another. The advantage from coördinating the work of a number of researchers should pay for a coördinator; also much depends on selecting the right problems and much on discontinuing work which for any reason is no longer promising. Of course, a department of research is ordinarily started with one man who calls

others to his assistance as the need grows; and happy is the industry that picks the right man to make the beginning and to direct the force that is later added.

When plant experimenting was put on a business basis, it became known as industrial research. This is of two fairly distinct types: (1) what may be called Research proper, which employs the small-scale, laboratory equipment of academic research and differs from it mainly in objective, and (2) Development, or the experimental application of research to industry, which is another name for invention. This introduces new problems in equipment and in methods.

Again, we may have: (a) Product Development or (b) Chemical Process Development. Ordinarily product development goes hand in hand with chemical process development, the emphasis being on one or the other, but in their methods and equipment requirements the two differ widely. Product development involves a study of properties and uses, leading, it may be, to exhaustive service tests, first in the laboratory and later under conditions of actual service. The purpose in any case is that of obtaining the product best suited to a specific use or a product well suited at a lower cost, or, possibly, a profitable use for a new product or by-product.

The laboratory equipment required in product development is that employed for physical and chemical tests. If these tests are those suggested by a proposed use, there may be advantage in exaggerating the severity of the conditions met in such use, in order that unpromising products may early be eliminated and only those that give fair promise of success be subjected to the test of actual service.

In chemical process development the problem is that of reducing the cost of operation, or improving the product, or both, and, when the results of research are to be translated into commercial production, of proceeding with reasonable safety and at minimum cost from laboratory-scale to plant-scale operation.

The development of a new or improved product implies, of course, the development of a new chemical process or one modified in respect to its operations or its raw materials.

In the exploitation of a new chemical process, or radical modification of an existing process, success is assured only as progress is gradual. To this end chemical process development is best undertaken in graduated steps or stages. Thus we have:

(A) First-stage, or unit-process, development, in which the first step is taken from the small,

laboratory scale to a somewhat larger scale, employing apparatus made of materials suitable for the construction of factory equipment, and large enough to make possible a proper study of yields and quality of product and give a supply of product sufficient for experimental use.

(B) Second-stage, or "semi-works," development, in which nearer approach is made to the conditions of commercial production by connecting in manufacturing sequence the various experimental units required. The semi-works plant so formed lends itself to a study of costs and to anticipation of the inevitable difficulties that come with manufacture better than do the unconnected units of unit-process development.

(C) Last-stage development in which production is initiated by the use of a unit or small group of units of the proposed full-sized manufacturing equipment, in order that process and product may be standardized and the market further exploited before routine, large-scale production is undertaken.

Too many have the impression that knowledge gained in research, if of potential value in industry, is ordinarily capable of immediate practical application. They have heard it said that research is a gamble, but in this they fail to distinguish between small-scale laboratory re-

search, which is relatively inexpensive, and the industrial exploitation of such research, or "development," which may be a costly procedure. They are surprised when told that it is not unsuccessful research that gives most cause for concern, but, rather the successful research, that is, the promising small-scale laboratory work which it is proposed to exploit in terms of an industrial process.

There is much wisdom in Baekeland's oft-quoted admonition: "Commit your blunders on a small scale and make your profits on a large scale." Research, even if negative in its immediate results, generally pays for itself in useful knowledge gained. In its early stages development also may be worth all it costs, but advanced development—the "semi-works" plant—highly profitable though it be as a means of avoiding failure in full-scale production, is a very unprofitable source of the information that research or earlier development should easily provide.

Let us assume that a given project appears to have good prospects of successful development, i.e., that it is scientifically sound, presents no apparent insurmountable difficulties of manufacture, and that the product involved meets a public need, or a demand that can be created. If success in development is to be attained, How much must

be invested? How long will it take? What is the reward of success? What is the penalty of failure?

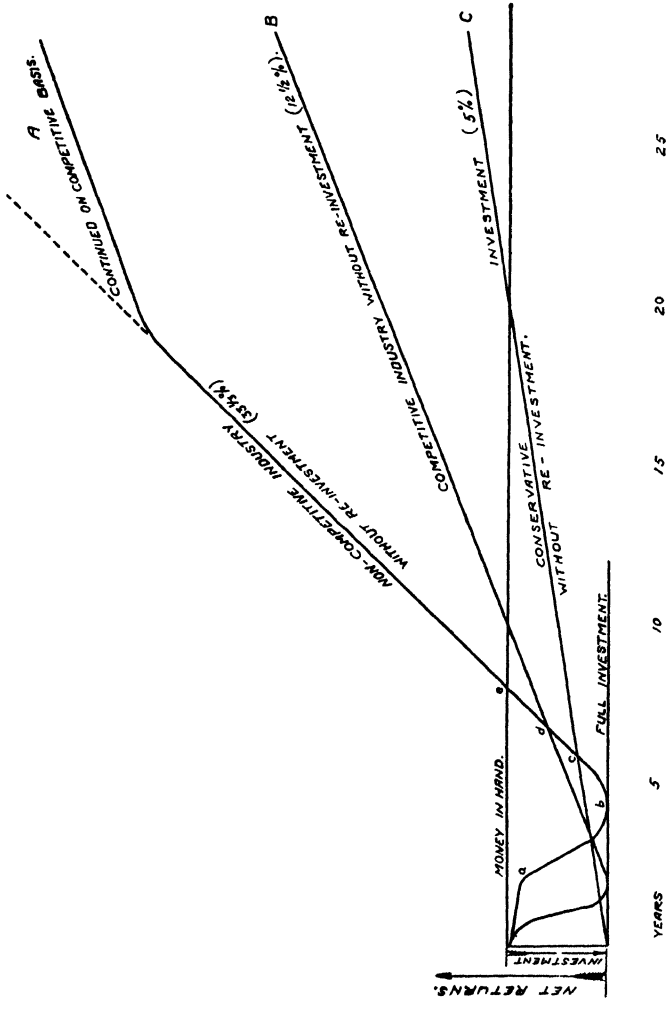
First let it be observed that the chance of being led into an unprofitable venture is considerably lessened if the project chosen for development is the most promising of a number of interesting research "successes" arising from intensive study of the industry such as progressive concerns carry on to-day.

Now let us assume that first-stage development has been completed, and the product, which has been repeatedly prepared in pound lots, and later in hundred pound lots, has found a reasonable measure of favor with prospective consumers; that a couple of years have been spent by one man and one or more helpers in research and such first-stage development, anticipating optimum conditions of manufacture as nearly as is possible in the small way with disconnected production units; that the precaution has been taken of employing, experimentally, materials of construction that would be feasible in full scale production, and that, under the conditions of time, temperature and what not, all of which appear equally practicable, quality and yields have been found satisfactory. If no radical departure from the industry's established conditions of manufacture

is required, cautious introduction direct into manufacture may be made with reasonable expectation of success. If, on the other hand, we are considering the production of a new product for which no previous manufacturing experience exists or is available, we then have a very different problem. We must introduce one or more steps to provide gradual transition from the small development scale to the factory scale, as outlined above, in order that we may the better study costs and the whole range of changed conditions imposed by large-scale production.

All this takes time, calls for faith on the part of everybody, and requires many times as much money as was spent in research and earlier development. Furthermore financial support must be obtained not for a few months only, but for several years, if need be, during which time expenses will be increasing rapidly; capital will be melting away without return. The road to success in new manufacture is long, and is strewn with the wreckage of attempted short-cuts from small-way experimenting, or none at all, into large-scale production.

Graphically represented, the course of a new project from the initial research through development into successful production is something like that shown in Fig. 2, in which *A* is the curve


A
CONTINUED ON COMPETITIVE BASIS.
B
COMPETITIVE INDUSTRY WITHOUT RE-INVESTMENT (12½%).
C
CONSERVATIVE INVESTMENT (5%)
WITHOUT RE-INVESTMENT.
NON-COMPETITIVE INDUSTRY (33⅓%)
WITHOUT RE-INVESTMENT
MONEY IN HAND.
FULL INVESTMENT.
INVESTMENT
NET RETURNS.
YEARS
5
10
15
20
25
a
b
c
d
e

of research, development, and successful production. By way of direct comparison *B* is given, depicting about what may be expected through investment of a like sum in successfully equipping for established competitive manufacture, while *C* is added to show the return from equal investment in "gilt-edge" securities.

If we follow curve *A*, it will be seen that expenditure starts off rather modestly (let us say with $10,000 the first year), and increases gradually with small-scale development until advanced development is undertaken (*a* on the curve).

Right here is the time for taking stock, and taking it most carefully, employing the combined wisdom gained in research, in small-way development, in related manufacture, and in the market. Advanced development means a period of rapidly growing expenditure, which will lead either to gratifying achievement and adequate return, or to disheartening failure and consuming loss. In some measure, at least, the reputation of the research man and the future confidence of his backers are at stake also. If the project is to be abandoned for reasons that can be anticipated let it be abandoned now; in another year or so the loss, in the event of failure, will be many-fold.

But, if after thorough examination from every

angle, the venture appears warranted, there will now be in order, investment in an experimental plant, one by which the cost of equipment and of raw materials may be kept to a minimum consistent with gaining a reasonably safe knowledge of future manufacturing requirements, yet a plant capable of turning out a salable product.

While from now on expenditure may be expected to increase rapidly, still if all goes well, in a couple of years from the beginning of such development, sales, which should be made as early as possible for the added benefit of customer criticism, should begin to provide profits in sufficient amount to off-set expenses (*b* on curve) and start the venture on the up-grade. While there is no regularity about this, of course, let us assume that the profits are those that later manufacture should be expected to realize, or say $33\frac{1}{3}$ per cent. At this rate, by about the end of the eighth year from the beginning of research (at *e* on the curve), the investment should have been recovered.

Such an adventure into new fields of manufacture may involve something like three years of uncertainty and doubt both for the financial man, who sees his capital being rapidly used up, with everything going out and nothing coming in, and for the research man who must have reasons

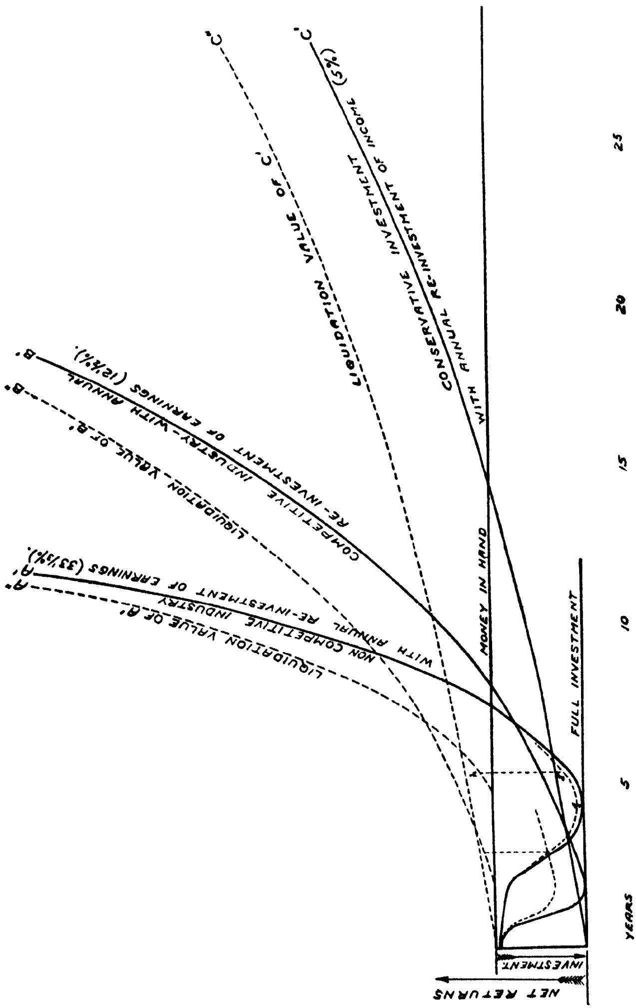

C'
C'
(5%)
CONSERVATIVE INVESTMENT OF INCOME
WITH ANNUAL RE-INVESTMENT OF INCOME
LIQUIDATION VALUE OF C'
B'
B'
COMPETITIVE INDUSTRY-WITH ANNUAL RE-INVESTMENT OF EARNINGS (12½%).
LIQUIDATION VALUE OF B'
A'
A'
NON COMPETITIVE INDUSTRY WITH ANNUAL RE-INVESTMENT OF EARNINGS (33⅓%).
LIQUIDATION VALUE OF A'
MONEY IN HAND
FULL INVESTMENT
INVESTMENT
NET RETURNS
YEARS
5
10
15
20
25

Figure 3

for assuring and reassuring first himself, and in turn his backers, that everything is taking its normal course and in due time will amply justify the venture. The duration of this period of suspense, the total cost of development, and the chance of ultimate success will depend probably more on the thoroughness of the initial research and development than on later resourcefulness.

If all goes well, the enterprise should pass conservative investment in its returns by perhaps the end of the fifth year (*c* on the curve) and by the end of another (*d*) catch up with investment in established, competitive manufacture. We have now a going business which, as indicated by the curve should continue on a highly profitable basis as long as the industry remains non-competitive or, we will say, during the life of such basic patents as may have been granted covering process or product. From then on the industry may be expected to take the regular course dictated by competition, and be followed, let us hope, by successful development projects still in their periods of major earnings, so separated in point of time that each has been able to support the next following during its unproductive years.

The danger of having too many of the drops in the curve (from *a* to *b*) at one time or in rapid

succession will be apparent, since the length of these periods of large expense without return cannot be definitely foretold and the increasing

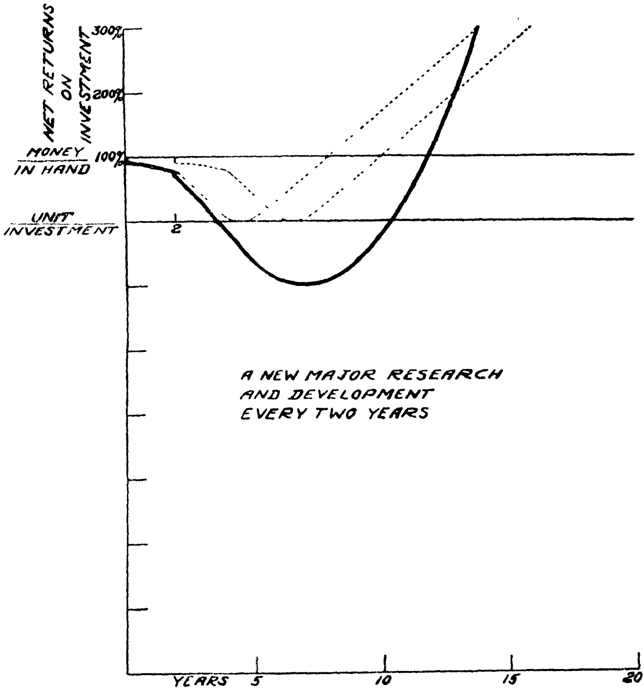


Figure 4

demand for capital might prove embarrassing if not disastrous. This danger is graphically shown in figures 4, 5, and 6.

Capital is not easily obtained for development projects. The banker as custodian of the people's money must be guided by last year's statement

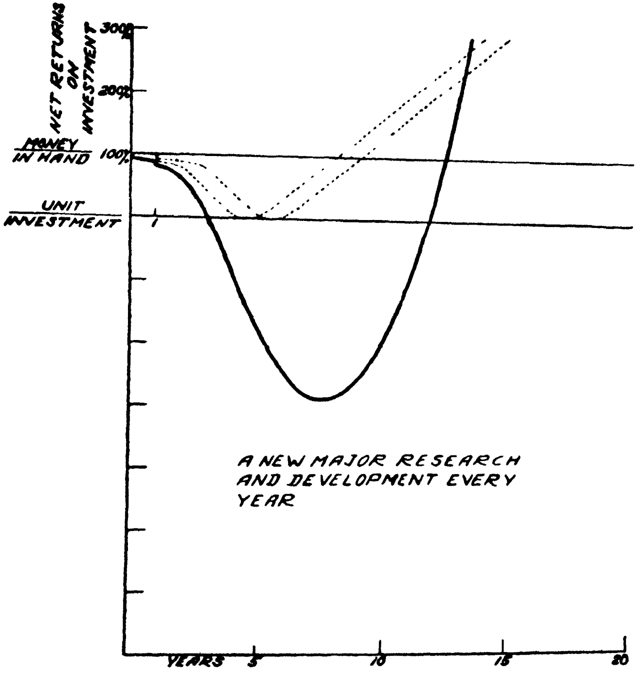


Figure 5

rather than next year's hope. In fact the vision and the faith that makes successful development possible may be difficult enough to communicate to a board of directors who best know their

industry's needs and possibilities. The conditions are unusual, however, that would warrant investing in development projects beyond that

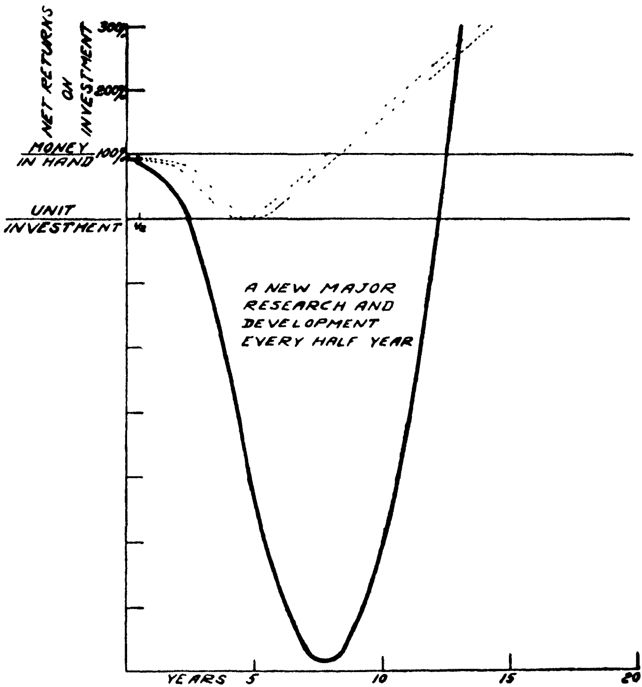


Figure 6

amount which would permit reasonable annual returns to the stock holder.

It must not be forgotten that when one is not

observing but is experiencing this drop in the curve, a future upward trend is neither as certain nor as apparent as it is on paper. But the period of large expense must not be permitted to become a period of discouragement. It may be difficult enough to keep up one's courage without the burden of financial worries. Worry can be avoided by keeping within one's means. Desire for early realization of the large returns promised by success, therefore, must not lead to indulgence in the luxury of launching a greater number of development projects than income or surplus warrants.

But there is a brighter picture. It is that of the research director who, working within his means, sees his first development project well into its earning stage before he starts another and who, employing sequence with proper interval, comes to see successful manufacture that has grown out of development amply justify if not directly support an expanding program of research and development. It may not show on the books as they are kept, but under normal conditions a successful major development project should be able eventually to support one or more new projects through the unproductive period, and in addition satisfy the stockholders' legitimate demand for regular dividends.

The financial possibilities of successful research and development are not fully indicated in curve A, Fig. 2, nor are they in curve A', Fig. 3, in which annual re-investment of earnings are shown, since it is evident that to an extent limited only by demand and available capital, larger sums may find opportunity for such profitable investment. For the benefit of comparison are shown B', re-investment curve for competitive industry, and C', "compound interest" curve of highly conservative investment.

We have followed the curve of successful development into profitable manufacture. An attempt has been made to answer the questions: How much must be invested? How long will it take? and, What is the reward of success? We have yet to consider What is the penalty of failure? Or, let us put it more broadly and optimistically, and ask instead, What may one hope to realize on withdrawal at any given time?

As already suggested, the auspicious time to withdraw from an unpromising project is before advanced development is started, and from a promising one, not until after a profitable industry has been established. It is like flying the Atlantic in that the nearer the goal, the greater the hazard in turning back while to quit is to court immediate disaster. The probable extent of

such disaster may be seen by consulting the dotted curve *A''*, Figure 3, which we may call the curve of liquidation values. It was plotted on the assumption that the salvage from an experimental plant is small, let us say 15 per cent of the first cost, and that there will have been twice as much spent for salaries, labor and materials as for equipment; that salaries, labor and materials may be considered as lost, and that, therefore, the liquidation value may be taken as only 5 per cent of the investment up to the time the project shall have become an assured success. Then valuation becomes that of a going business instead of unprofitable knowledge and equipment. We have assumed in curve *A''* that about a year after the new industry has begun to make money it should represent an alluring investment and that liquidation value should then be not less than the capital represented in the venture plus the profits earned. The transition from a low to a high liquidation value (*g* to *h* on the curve) is indicated as being abrupt because if the enterprise is to be liquidated it will be either as an abandoned plant of junk value only, or as a profitable business. However, at any time after rounding the curve (at *f*), profitable sale becomes a possibility. This is indicated by extension of both the low-value and the high-value portions of the curve on either side of the line of transition.

The corresponding curve of investment in established industry (*B''*) is based on the assumption that abandoned equipment is salable at half original cost and that one-third of the whole sum expended to get into profitable production has been for salaries, wages, and materials, and two-thirds for equipment. Curve, *C''*, is drawn to indicate the possibility of complete withdrawal from highly conservative investment at any time without loss.

The adage: "Nothing fails like a failure nor succeeds like success" finds nowhere greater justification than in the development of new industrial projects. If development can be carried through to successful production, capitalization should be possible at a figure well above the whole cost of research and development. In fact expansion will be limited only by the commercial possibilities of the field, and may reach an order of magnitude in comparison with which the original investment will look small. Curve *A''*, like curve *A'*, considerably understates the possibilities of successful development and is chiefly of interest in that part which indicates the losses that may result from a non-feasible venture, a faint heart, or failing resources.

Perhaps more than thirty per cent may be thought of as an excessive return for any kind of investment. The answer may be found in a

comparison of curves C'' and B'' with A''. In gilt edge securities, from the first year on there may be realized on liquidation 100 per cent of the investment and earnings. In getting into competitive industry there is rapid shrinkage of capital and an unproductive period together with some hazard and a possible liquidation value of only one-third of the investment. As a result capital demands promise of commensurately higher returns.

In launching a new development project the hazard of failure is considerably greater than in established manufacture and the unproductive period during which capital melts away with no assurance of return, is not only much longer but is of uncertain duration. If the returns promised in the event of success were not proportionately large, capital would not be justified in assuming the hazard. That, with good management, the hazard is warranted, however, is attested by the fact that the industrial securities considered of the highest grade to-day are those which have back of them a well organized and well directed program of research.

It is by such a route that our more recent material progress has come. Traveled with difficulty though it is, it is one beset by relatively few dangers when compared to the treacherous path

of the lone inventor. As a matter of fact the route by which organized discovery and invention is adding so rapidly to the wealth of modern nations is a broad highway open to all, and may be traversed with reasonable assurance of a safe and profitable journey by all those who observe the measures prescribed for safe travel. Along this highway have come whole new industries; also new processes and new products that have revolutionized long established industries. Along this highway progress is coming with quickening pace; while destroying obsolescence is overtaking the slothful.

We have profited greatly in a material way from industrial research. The returns have increased at a rapid rate since we organized it and put it on a business basis. How may we insure continued increasing returns?

CHAPTER XI

BREAD UPON THE WATERS

THIS is to be a sermon. For sermonizing, the less understandable the text the better; it provides latitude. Those cryptic words of the sage, beginning: "Cast thy bread upon the waters" have inspired many a discourse on the blessedness of giving. For those less inclined to generosity, the second part: "for thou shalt find it after many days" provides a needed measure of reassurance. We have only to modernize the exhortation to read: "for thou shalt find increasing returns after many days," and we have a text admirably suited to our present purpose.

So to the researcher in pure science we would say: "Yours is the blessedness of giving your life to creative work"; to the public spirited: "Yours the privilege of abetting such work for the benefit of your own generation and the generations yet unborn"; to the man of business: "Yours the opportunity to reap rich rewards for yourself and for your own generation." Meanwhile, it will be well to bear in mind that the increasing

returns that we have found after many days have originated most often in work inspired by no thought of personal gain.

Are we highly appreciative of the benefits of electricity, that faithful servant that provides a light, a cooling breeze, or power for chilling cold, as we decree? that toasts our bread, irons our clothes, and runs the furnace that keeps us warm? that, with the swiftness of light, carries to the far ends of earth our written and our spoken words, and gets us about with pleasing speed and comfort? Then let us not forget Gilbert, Volta and those who came after, and more especially Faraday, whose patient, penetrating researches laid the foundation for our widespread realization of these benefits. It was none less than Gladstone, who naïvely enquired of Faraday: "But, after all, what use is it?" Then Faraday's rejoinder: "Why Sir, there is every probability that you will soon be able to tax it." In our country the gross receipts from distribution of electric current in 1931 were nearly two billion dollars. Unfortunately the corresponding figure for Great Britain is not at hand, nor that showing the gross income of all British industry in Gladstone's time. The presumption is, however, that today's public revenue from the outgrowth of Faraday's researches would have interested Gladstone.

But before the Gladstones were able to tax it there remained much work, and personal sacrifice, for Morse, and Bell, and Hoskins, and Edison, and Coolidge, and Langmuir, and the great army of present-day trained investigators who have wrought excellence and efficiency out of early-day crudity.

Is it radio that seems worthwhile; radio that brings to our firesides grand opera or syncopated strains as suits our fancy? Let us not forget Maxwell and his mathematical exposition of Faraday's electro-magnetic phenomena, predicting the long "light" waves; nor Hertz who later experimentally produced them, thus paving the way for Marconi, DeForest, and the many others who have developed these initial experiments.

Is it the materials that add to beauty and comfort—is it the pleasing hues of raiment? It was Perkin who introduced to us the brilliant colors that lurk in coal tar awaiting the fairy wand of chemical research, and Woehler who removed the veil that hid from our eyes the limitless possibilities of organic synthesis.

Is it earth's increasing productiveness? But for Liebig and those who followed we should have no present problem of a surfeit in agriculture, but instead, the prospect of recurring famine.

But, most important of all, Is it the beneficence

of present-day medicine, curative and preventive; of anaesthesia, and the miracles of modern surgery, for which we give thanks? Let us not forget Pasteur, and Lister, and Koch, and Ehrlich, and Reed and his brave band, nor the small army of present-day organized workers intent on ridding us of our remaining scourges and adding to the span of life.

In practically every instance the necessary beginning was made through the patient researches of those who sought no personal reward, of those doing work which at the time was thought by men of affairs to be of no consequence.

And not for one generation alone, is this creative work. "While the physical structures of men are decaying, the facts he (the researcher) has learned are ever doing new service. Antitoxic devices will be increasing when locomotives are forgotten. Magnetic induction will work when the pyramids have blown away."—Whitney and Hawkins in *Profitable Practice in Industrial Research.*

It must not be forgotten that the foundations of our greatest present-day advances were laid a generation or more ago. In the utilization of new knowledge of a far-reaching, fundamental character there is a lag, but it is rapidly growing shorter. Considering the army of trained workers

now supported by industry for the application of research, the danger is rather that we shall soon outrun our discovery of fundamental new knowledge. What shall we do, it has been asked, when there is no more research to apply? As great as is the need for continued effort in the application of existing knowledge, the old law of diminishing returns soon begins to take its toll unless new knowledge comes and removes the barrier to increasing returns. Our new *law of increasing returns* demands, if we would erect a superstructure of industrial application, that the foundation of progress, which is research in the domain of pure science, be strengthened and extended. Of pure science research there is no danger of overproduction. Instead, its field of opportunity expands with every advance, its horizons ever recede, its frontiers know no end; and every new frontier means new territory for cultivation. Industry and the nation owe to research in the domain of pure science continued unstinted support. Industry was the first to apply the results of scientific research, but we as a nation will not reap the full benefits of research until our means to health, and our economic and social orders, also have received their full share of its benefits.

As for health—supplementing able work already

in progress, we have recently established the National Institute of Health. The outlook is promising, for the program emphasizes fundamental chemico-medical research.

As for economics and sociology—we are not now doing as well as we know how. When the average man no longer pokes fun at fact-finding bodies, we shall have taken a big step toward better things.

As for industry—if we do not become and continue as much interested in adequate promotion of research in pure science as we are now interested in its exploitation, we shall find the indispensable, life-giving stream of new knowledge drying up at its source.

But not only must we be definitely committed to the promotion of pure-science research and its application, but also to *consistent, continued* promotion. Discontinued effort means irreparable loss.

The industrialist puts aside a surplus that dividends may be maintained uninterruptedly. Why not a surplus that the increment of new knowledge of value to his industry be not abated? A surplus of new knowledge is a real asset to any industry, more real in the long run in determining industrial leadership than are raw materials or patent rights. New knowledge becomes tomor-

row's investment of greatest value. Such intellectual property has not acquired the status of an asset in to-day's bookkeeping. Perhaps sound financing would dictate that it never should, but it will surely appear in tomorrow's achievements. Men have acquired monopolistic control of raw materials and of patent rights. If they are not also acquiring a commensurate surplus of new knowledge through research, they will lose their monopolistic hold.

Our more progressive industries are endeavoring to maintain a consistent program of research, but consistent, sustained research has not yet acquired the status of an obligation of sound management in the minds of many of those in control of business finance. Too often has research been thought of as a luxury to be indulged during a period of large profits and to be discontinued when dividends can no longer be fully maintained. Better to cancel fire insurance than to drop the only insurance against retrogression. It is the privilege of the industrialist to profit a little while he adds vastly more to the wealth of all. He will succeed in proportion as his creative effort is not intermittent and wasteful but is sustained and efficient.

We are wont to recount the triumphs of science in terms of material benefits only. These are

more tangible; but are they more real than the spiritual benefits? Along with these creature comforts, our new knowledge of Nature's ways has brought us a new outlook on life. Nature is no longer capricious, but reasonable; no longer seeking our destruction, but lending a willing hand in all our endeavors. Paralyzing fear has given place to confidence born of knowledge and resourcefulness. Instead of being filled with forebodings of what dire thing may befall us, we are instead filled with a desire to learn how some new blessing may be ours. The mysteries of Nature are greater than ever but they have been removed to the frontier of pure science, where they no longer terrify children, young or old, but instead provide zest to those who would further extend the frontier of knowledge and thus again push back the borderland of mystery. Science has provided and must continue to provide material benefits, for without these the spirit withers, borne down by the struggle for bare existence. "Man is essentially spiritual," said that dean of research directors, Willis R. Whitney, addressing the American Philosophical Society, "but his tokens of values, his media of exchange, the flowers of goodwill to others, call for material even mechanical, devices. The Greek slave, the Egyptian fellah and the man-with-the-hoe de-

veloped into the modern, less enslaved philosopher who sees that man is essentially spiritual. If there is one thing modern mechanical civilization can do, it is to free people from slavery and strew spiritual opportunity along their paths."

But we are awakening to the fact that the viewpoint and method of research are applicable in ways we have been neglecting, and we begin to suspect that we shall continue such neglect at our peril. In our social institutions, in our government, we are lagging behind. It took Priestley two months to reach our shores; we now make the voyage in less than a week. But do we note the same degree of progress in the political agencies whose representatives extended him a welcome? It would seem paramount to our general welfare that in the other parts of our civilization we catch up with material progress.

CHAPTER XII

CATCHING UP WITH MATERIAL PROGRESS

CONSCIOUS of maladjustment in our civilization we cast about for some authoritative confirmation of the fact and assignment of the cause. We find it in the official summary issued in January 1933 of the report of President Hoover's Committee on Recent Social Trends in the United States. We are told that while we have been pressing on in the development and application of the physical sciences, the science of human relations has been comparatively neglected and what we have learned has not found general application. In many parts of our civilization we have been merely drifting while the physical sciences and technology have been proceeding according to chart and compass and under a good head of steam. The result we are told has been maladjustment from different rates of change, a lack of coördination in our social machine, all parts of which—agriculture, labor, industry, government, education, religion, science—must function in unison, if it is not

frequently to be laid up for repairs. The committee states that "these interrelated changes which are going forward in such bewildering variety and at such varying speeds threaten grave dangers with one hand while with the other hand they hold out the promise to further betterment to mankind." After being reminded that "the objective of any conscious control over the process is to secure a better adjustment between inherited nature and culture," we are told that "the means of social control is social discovery and the wider adoption of new knowledge." We find encouragement in the statement that "a considerable amount of such work is now being done in universities and independent research institutes and the results are seen in the increasing penetration of social technology into public welfare work, public health education, social work and the courts." The belief is expressed that "while some of these inquiries may be fragmentary and often unrelated or inadequately related, there should nevertheless be important findings and inventions of great value to society." We are informed and encouraged by the following: "While the most recent phase of American development in the social field has been the recognition of the necessity of fact-finding agencies and equipment, and their actual establishment,

the next phase of advance may find more emphasis upon interpretation and synthesis than the last."

It is not possible of course, by merely employing a few quotations, to do justice of this able, comprehensive official summary of the Committee's inquiry, an inquiry unique in our governmental history; furthermore, it is unnecessary since it can be read by all, and has been read by many. It is of interest further to note, however, that a comprehensive discussion of the problems provided by our cycles of industrial prosperity and depression is concluded with the declaration that "to maintain the balance of our economic mechanism is a challenge to all the imagination, the scientific insight and the constructive ability which we and our children can muster"; also that, in the opinion of the Committee, "we may look for important contributions from individual thinkers with a point of view from which the focusing of social problems and their constructive integration is not excluded but emphasized."

An important individual contribution may have been made, it would seem, by Adelbert Ames, Jr., Research Professor of Physiological Optics at the Medical School of Dartmouth College; a rather unexpected source for an important generalization in economics. At least

it is a contribution of particular interest from the standpoint of research and one which has received favorable comment from a number of forward-looking economists. The Ames contribution appeared in January 1932, as a supplement to the Dartmouth Magazine. It was entitled "Progress and Prosperity; A Suggested Program."

Overproduction has long been assumed to be an important factor in bringing about business depressions. It has remained for Ames to classify human activities on the basis of the extent to which the products of such activities can be overproduced.

Briefly stated, the classes into which Ames divides human activities are these:

I. Those that cannot be overproduced. Among these is scientific research.

II. Those that are overproduced only when production exceeds the ultimate need. Included are: parks, highways, other public works.

III. Those in which overproduction occurs when supply exceeds the near-future need. For example: houses, automobiles, and equipment in general that is subject to obsolescence.

IV. Those in which overproduction occurs when supply exceeds the immediate need. Such are: clothing, food, heat.

In other words "overproduction" is not just

overproduction of anything, but of those goods only which must be consumed immediately or relatively soon, if they are not to perish.

Ames makes the interesting point that a *depression* may end with the consumption of existing perishable or near-perishable goods, but *prosperity* is dependent on new developments which come only through research and its application. "From the old economic point of view," says Ames, "such new developments may be looked upon merely as supplying a new demand, and that prosperity comes when new demands are created"; but, he continues, "an analysis of the facts shows that that is only part of the story, and that a new factor of a different and more fundamental nature comes into operation with such developments."

"It is this. New developments, such as mentioned" (telegraph, telephone, steam engine, electric light) "enable individuals to do more in less time—they increase the individual's horse power, so to speak, or the number of slaves at his bidding. In other words, they increase his capacity for economic activity."

"Such increase in individual capacity for economic activity means, and it alone means, increase in economic well being. Gold, silver, credit, economic wealth, national income, though they

may be indications, and not very accurate at that, of the existence of a high capacity for economic activity, do not in themselves make economic well being."

Ames believes that "at least in this country the rapidity with which new developments could be brought out would be somewhere near proportional to the amount of brains and labor that is devoted to the task." As a practical means for sustained national well-being he believes some plan should be adopted for encouraging capital to enter the field of new developments.

There is more to Ames' interesting generalization. Thus, not only would he divert capital and labor from overproduction of perishable and near-perishable goods into research and new developments, but also into the promotion of public health, education, the fine arts, music, religion (as distinguished from theology), recreations and amusements, fully expecting that these further means to the advancement of our civilization would be adequately and easily supported by the wealth coming out of research and new developments, and by the savings from avoidance of idleness due to overproduction.

Ames' point of departure from the classical economics is in his emphasis on change as the law of the universe, not excepting man's own institu-

tions. The old economic order aimed at stabilization. Ames sees the futility of it and seeks to make adjustment to, and derive benefit from, change.

Discussing Ames' "new economic philosophy," Professor Cabot, of Harvard University's Graduate School of Business Administration, says: "If our mental attitude were altered so as to place due emphasis on change, we might look more hopefully on the future of democratic institutions"—"The thing he" (Ames) "has given us is a sketch of an economic philosophy which if carefully studied by competent men, might furnish the basis of a successful national policy."

For the successful operation of such a national policy, however, or any other, the average citizen needs to be educated to an appreciative understanding of the research viewpoint. Open-mindedness must be inculcated. The hope that open-mindedness will eventually characterize our approach to all problems of national economy should not be considered utopian. It follows from a consideration of the origin of our present-day successes in the physical, chemical, and biological sciences. These would never have been realized but for the intellectual honesty that has characterized science from the beginning. Scientific men are not by nature more honest

in their mental processes than other men. But intellectual honesty is the unwritten law, the "public sentiment," of modern science; non-conformity brings scientific social ostracism. Like the religious faith that made martyrs of early scientists, science itself was fortunate in having its beginnings in martyrdom. A Friar Bacon and a Galileo willing to suffer persecution and imprisonment for their beliefs; these and others who followed, not excluding men of the past century—Pasteur, Darwin, Huxley, who were persecuted only less primitively—all these helped to establish and preserve the tradition of open-mindedness as the *sine qua non* of progress in science. All that has followed is a corollary of this, namely, personally disinterested, intelligent, thorough, tireless pursuit of knowledge concerning facts and their interdependence; ever appreciating—and in this lies the secret of all progress—that knowledge is never complete, that generalizations—hypotheses, theories, laws—which we sometimes refer to as the "truth" are of value only as guides to further knowledge. In science the whole "truth" has never been revealed and will never be. Thus is continued progress assured, and unlimited.

We may know that we are making progress toward open-mindedness when, one by one,

subjects now taboo as being "controversial," that is, personal and emotional, become recognized as legitimate subjects of inquiry. We shall have no fears concerning the eventual adjustment of society to the revolutionizing works of material science when open-minded approach to our problems of human relations becomes the demand of public sentiment. It must be a part of the instruction of the rising generation. It is coming, perhaps sooner than we have dared hope. The morning paper quotes a prominent educator as declaring that even the junior high school should inculcate toward controversial social and political issues an attitude that is impersonal and scientific.

But while a scientific approach alone offers hope of solution of our social and political problems, it by no means follows that only those trained in science are qualified to lead. Ability in leadership is largely a native endowment and tends to be self-asserting. We find it in all walks of life. In a democracy hope lies rather in education of the masses to better appreciation of the necessity of the impersonal, scientific approach. Then will we have more constructive leadership and have the public sentiment to demand it. But also more and more will science have drawn to its ranks men qualified for and interested in political leadership. Their main advantage over

those who merely understand the method of science and appreciate its potentialities will lie in their better appreciation of its limitations as well. They will better understand that science can never rise above established fact, just, as we say: "no man's judgment can rise above his information." Harvard University has chosen a second president from its chemistry faculty. Neither Eliot nor Conant, however, were chosen because they were chemists, though each no doubt was made a broader man by his training in this all-pervading science.

As to research in social science, we may expect it to profit from the progress made in biology, and in chemistry before it. Comte, French philosopher, prophesied a hundred years ago, that sociology would be the last science to develop. He placed the sciences in the order: Mathematics, Astronomy, Physics, Chemistry, Biology, Sociology, each dependent on those preceding it. We need not reproach ourselves for not having developed sociology along with and at the same rate with physics, chemistry and biology. It has had to wait in some measure on biology, and especially physiology and psychology. These also are in the way of receiving great help from chemistry, just as chemistry was a mere descriptive science, instead of the exact science it is

to-day, until it received aid from physics and mathematics. The Committee on Recent Social Trends is impressed by the possibility of chemistry's aiding sociology through means already referred to in other connections. Speaking of *Environment Influences on Quality of Peoples* it says: "There is one possible type of influence which may be overwhelming if it should be developed. This is the influence of physiological invention. One illustration is the possible influence of new chemical knowledge on the regulation, growth and functioning of the hormones, particularly those associated with certain endocrine glands, with possibly astonishing effects on personality and the quality of the population."

But, in a sense, astonishing effects have already been brought about in the population by the physical sciences and technology. We are wont to say that the past century of progress has wrought greater changes in man's *environment* than during all of the centuries gone before. We point to the quarter million miles of railroad and the four hundred fifty billion "ton miles" carried during the last prosperous year, bringing in six billion dollars of revenue; to the twenty six million motor vehicles; to the hundred million miles flown by airplanes; to the twenty million telephones in use, the five billions invested in equip-

ment, and the four hundred millions spent in extension of service during one year; to telegraphy and its hundred millions of revenue; to the fifteen million radio receiving sets, reaching half of the hundred twenty-three millions of population; to a total energy supply equivalent to a billion tons of coal annually, and electric output of a hundred billion kilowatt hours; to the fifty million tons of steel produced, the million men employed in making machinery and the six hundred millions worth of agricultural machinery produced in one prosperous year.—All these we think of as a radical change of environment, but the important thing is the *effective* change in the people themselves. In a practical sense man has evolved, and at a tremendous rate. John W. Draper, first president of the American Chemical Society saw it before the days of the telephone, when the greater part of our advance had only begun. Listen to his inaugural words, uttered in 1876: "Telegraphic wires are, strictly speaking, continuations of the centrifugal nerves and we are not without reason for believing that it is the same influence which is active in both cases."

"In a scientific point of view such improvements in the organs of receiving external impression, such extensions in the distances to which the results of intellectual acts and the dictates

of the will may be conveyed constitute a true development, an evolution none the less real though it may be of an artificial kind. If we reflect carefully on these things, bearing in mind what is now known of the course of development in the animal series, we shall not fail to remark what a singular interest gathers round these artificial developments—artificial they can scarcely be called, since they themselves have arisen interiorly. They are the result of intellectual acts. Man has been developing himself. He, so far as the earth is concerned, is becoming omnipresent. The electrical nerves of society are spread in a plexus all over Europe and America; their commissural strands run under the Atlantic and the Pacific."

Since Draper's time man has developed legs that carry him on the public highway at a mile a minute; he has developed wings that enable him to out-strip the bird in flight; he has developed a voice that can be heard half round the world. And so it has come about that the continent is spanned in a day; the populations of our cities have sought homes in outlying places; the nations converse like next door neighbors of an earlier day. Yet the old governmental units and boundaries survive.

Signally have we evolved as individuals during

the past century through our use of new knowledge concerning matter and energy. Will the next century see a like acceleration in the evolution of society through new knowledge in human relations gained and applied?

We may with reason expect that eventually we shall have freedom from recurring periods of economic depression. These have caused some even to doubt that we have in fact progressed. We may with reason demand that the disturbing readjustments that accompany all industrial progress shall not long continue to inflict undue hardship on individual members of society. But a holiday from research in the physical and biological sciences we cannot and should not have; not less of these, but much more of sociologic, including economic, research is the need.

So let fact-finding concerning our social order continue even though the mass of data accumulated become a maze. Chemistry for a century was a confusing array of unrelated facts. Then came Cannizarro, Mendeléef, Kekule, Lewis, Langmuir, Bohr, each lighting the way with revealing generalization. Thus will it be in our new science of sociology. Our workers in physics, chemistry, and biology will bring us an increasing measure of health, wealth, and leisure; we shall look to our open-minded workers in sociology,

the prophets and seers of our time, to point the way to ever better use and enjoyment of our new-found health, wealth, and leisure.

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